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SUPPLEMENT 1

HIGH MODULUS, HIGH TEMPERATURE GLASS FIBERS FOR REINFORCED PLASTICS

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Gentlemen:

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At the request of the Plastics Branch, Nonmetallic Materials Laboratory, Materials Central, WADD, a copy of the technical report covering activity of this organization under the subject contract is attached for your information and retention.

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Very truly yours,

OWENS-CORNING FIBERGLAS CORPORATION

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ARM/js
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FOREWORD

This report was prepared by Messrs. G. R. Machlan, C. J. Stalego, R. L. Tiede, A. B. Isham, and D. E. Caramante of Owens-Corning Fiberglas Corporation under Project No. 7340, "Non-Metallic and Composite Materials," Task No. 73400, "Organic and Inorganic Plastics," and was administered under the direction of the Materials Central, Directorate of Advanced Systems Technology, Wright Air Development Division, with Mr. G. P. Peterson acting as project engineer.

This report covers the period of work from April 15, 1959 to March 30, 1960.

Acknowledgement is made to Dr. F. V. Tooley, University of Illinois, for his services as consultant on this investigation.

ABSTRACT

An exploratory research investigation to determine the feasibility of producing glass fibers which retain useful properties at temperatures up to 2500°F resulted in the development of fibers which had a strength of 110,000 psi at 1800°F, an elastic modulus of 12.8 x 10^6 psi at room temperature, and a specific gravity of 2.53.

A program to improve the strength properties of laminates made from the high modulus glass developed in Supplement I of the contract resulted in laminates which had wet strengths at least equivalent to similar "E" glass laminates and an increase of 34 per cent in wet flexural modulus.

A program to develop unidirectional, non-woven, preimpregnated reinforcement which would produce laminates having very high strength yielded laminates which had a dry flexural strength of 265,000 psi and a dry flexural modulus of 7.81 x 10^6 psi.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

H. S. SCHWARTZ
Chief, Plastics Branch
Nonmetallic Materials Laboratory
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HIGH MODULUS, HIGH TEMPERATURE GLASS FIBERS FOR REINFORCED PLASTICS

INTRODUCTION

Fibrous glass reinforced plastics have many advantages over competitive materials for many applications. Even greater application of these materials to aircraft and missile construction would be possible if greater strength, stiffness, and temperature resistance could be achieved. This report covers investigations directed toward improvement in each of these properties.

The high temperature glass investigation is an exploratory program to determine the feasibility of producing glass fibers which have much greater strength at higher temperatures than any fibers now available for plastic reinforcement.

The high modulus glass investigation is a continuation of previous work on beryllia-containing high modulus glasses. This report[1] deals with the application of the high modulus glass fibers to the development of high modulus plastic laminates which have strength properties at least equivalent to standard "E" glass laminates.

The high strength investigation explored the possibility of developing a unidirectional, non-woven strand reinforced plastic which would have strength properties superior to similar laminates presently available.

This report has been prepared so that each of these topics are treated as separate phases; complete with introduction, summary, recommendations, and discussion. This format was selected because of the diversity of subject matter. A brief summary of each topic is given below but for a more complete summary and for recommendations the reader is referred to the individual Phase reports.

SUMMARY

High Temperature Glass Fibers

The objective of this exploratory program was to find a glass which had a strength of 250,000 psi and a modulus of 14×10^6 psi at 2500°F with a specific gravity of less than 3.0. No glass composition was found which could be drawn from a bushing similar to standard fiber-forming bushings which reached these target properties. A fiber was developed which had a tensile strength of 124,000 psi at 1900°F and an elastic modulus of 12.6×10^6 psi at room temperature. Several compositions were found which were nearly equivalent to this highest value and because

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[1] Manuscript released by authors December, 1960, for publication as a WADD Technical Report.

of considerations of ease of forming, viscous yield at high temperatures, and general resistance for long exposure to high temperatures, another composition, X-815, which has a tensile strength of 110,000 psi at 1800°F, an elastic modulus of 12.8×10^6 psi at room temperature and a specific gravity of 2.53 was selected as one of the best compositions for further evaluation and study.

Several hundred compositions have been investigated which might yield high temperature glasses. Those compositions which did form glasses and which could be formed into fibers were investigated for their temperature resistance, strength, modulus, and specific gravity.

Improvement in High Modulus Glass Laminates

At the conclusion of the previous work, Contract AF 33(616)-5802, Supplement I, a substantial increase in laminate modulus had been achieved but strengths of the high modulus laminates were generally lower than similar "E" glass moldings. It was the objective of this investigation to obtain laminates using the high modulus glass which had strength properties at least equivalent to those of "E" glass.

The high modulus glass was produced only in 51 filament strand in comparison to standard 204 filament strand of "E" glass. An investigation to determine the effect of this difference in yarn construction proved that it could not have been the cause of the poor strengths obtained with the high modulus glass.

An investigation to improve the cleaning or size removal from the high modulus strand gave no substantial improvement in strength over the standard heat cleaning methods used in the earlier work.

An investigation of various standard finishes, resin matrices, and reinforcement structures did yield high modulus laminates which equalled or surpassed similar "E" glass laminates in strength properties and elastic modulus. The selection of the proper resin-finish system and reinforcement structure gave wet strengths 11 per cent higher than similar "E" glass laminates and a 34 per cent increase in wet flexural modulus.

A general concept of how the high modulus glass may be successfully employed has been formulated as a result of this investigation.

High Modulus, High Strength Plastic Laminates Using Non-Woven Fiber Reinforcement

The objective of this investigation was to develop a non-woven pre-impregnated reinforcement suitable for practical molding which would yield molded products of superior strength.

Using "E" glass with a room temperature resin, all target properties were exceeded. Using Paraplex AP-174 resin and "E" glass, a dry flexural strength of 265,000 psi, a wet flexural strength of 247,000 psi and a dry flexural modulus of 7.81×10^6 psi were obtained.

Using "E" glass with a heat resistant resin all target properties except the flexural strength at 500°F after one half hour at 500°F were exceeded.

Using the high modulus glass and the room temperature resin, all target properties were equalled or exceeded. Using Paraplex AP-174 resin and YM31A glass, a dry flexural strength of 268,000 psi, a wet flexural strength of 210,000 psi and a dry flexural modulus of 10.5×10^6 psi were obtained.

PHASE I

HIGH TEMPERATURE, HIGH MODULUS GLASS CONTINUOUS FIBERS

INTRODUCTION

Glass fibers which retain their high strength to very high temperatures are needed for the development of reinforced plastics for high temperature applications. The target properties in the development of fibers for these uses are a strength at 2500°F of 250,000 psi; a fiber modulus of 14,000,000 psi at 2500°F; and a specific gravity less than 3.0.

Work on the development of fibers with these target properties was done during the past three quarters under Supplement No. 2 of AF 33(616)-5802.

SUMMARY

A total of 327 experimental batches was studied to determine the suitability of resulting glasses for formation of fibers for use at high temperatures. A small electrically heated hot stage observed with a binocular microscope was used to evaluate 302 of these batches for approximations of melting and liquidus temperatures as well as determinations of comparative viscosities.

Of the most promising compositions, 79 were selected for evaluation of attenuation performance in the refractory metal single hole bushing and for measurement of filament properties.

Qualitative tests were made of comparative temperature resistance by heating bundles of fibers in a muffle furnace at several temperatures to determine the temperature at which fibers became weak and brittle.

Quantitative measurements of tensile strengths and tensile moduli were made on the most temperature resistant fibers produced. Nine glasses having the best values of tensile strength at high temperature, refractoriness, and Young's modulus are listed in Table I.

Glass X-815 was tentatively chosen as the most desirable composition on the basis of physical properties and favorable forming characteristics. Further property measurements were made and samples prepared for testing in small bar laminates.

TABLE I

NINE GLASSES HAVING BEST TENSILE STRENGTHS,
REFRACTORINESS, AND YOUNG'S MODULUS AT HIGH TEMPERATURE

Glass #	Tensile Strength 10^3 psi		Young's Modulus at Room Temperature 10^6 psi	Appearance after 30 min. @ 1800°F	2000°F	2200°F
X-798	161	1800°F	11.8	strong	strong	weak
X-814	193	1800°F	12.5	strong	strong	weak
X-815	110	1800°F	12.8	strong	strong	strong
X-879	210	1800°F	11.3	strong	strong	poor
X-906	93*	1800°F		strong	weak	--
X-931	195	1500°F		strong	strong	strong
X-977	92*	1800°F		strong***	brittle	brittle
X-1091	31**	1800°F		strong	strong	weak
X-1096	66	1800°F	13.5	strong	strong	strong

*No yield
**Yields at 1800°F, but gave highest strengths at lower temperatures.
***Coarse fibers tested may have influenced results.

Two new positions were installed to facilitate the study of the effect of thermal conditioning of glass, forming temperature, tip geometry, and ambient conditions on physical properties of fibers of experimental high temperature glasses. It was found that room temperature strengths of fibers of experimental glasses could be improved by variations in forming techniques, but that strengths were usually about half that considered normal for "E" glass.

An attempt was made to melt X-815 in an arc furnace of the type used for electrocast refractories. This was unsuccessful because of the inability of the melt to conduct current.

Studies on the effect of proprietary surface coatings on temperature resistance of discontinuous or wool type fibers indicated that temperature resistance can be increased 150°F to 800°F dependent on type of glass used.

RECOMMENDATIONS

The following steps should be taken in pursuing further the development of glass fibers for use at high temperatures.

1. Retest the most promising compositions already investigated and select from them what appears to be the most suitable composition for production of high temperature fibers.
2. From the selected composition produce multiple filament strands for testing in plastic or inorganic laminates.
3. Attempts should be made to evaluate the effect of process variables, such as thermal history of the glass, forming temperature, tip geometry, and ambient conditions (including atmosphere) on the strength of fibers of the selected composition with the object of producing high temperature fibers with room temperature strength at least as good as present production glasses.
4. Additional composition work is not recommended. The probability of finding glass formulations, with the possible exception of beryllium oxide compositions, which yield glasses having significantly better high temperature properties is very slight.
5. The effect of certain proprietary surface treatments on the strength of continuous filaments at high temperatures should be determined.

DISCUSSION

The development of high temperature, high modulus fibers involves the selection of compositions which may produce high temperature glasses, a screening evaluation of these compositions to determine which ones may be formed into fibers, production of sample quantities of fibers of promising glasses to determine qualitatively their temperature resistance, and finally, measurement of modulus and tensile strength of fibers at room temperature and at elevated temperatures.

Selection of Glass Compositions

The compositions selected for evaluation may be classified into three groups.

1. Compositions which are virtually certain to form glasses which can be fiberized at proper temperatures and which are virtually certain to be more temperature resistant than common glasses. Glasses X-799, X-798, X-815, and X-897 are typical examples, although by no means the only examples of this type of glass.
2. Compositions which probably will not form glasses from which filaments can be drawn and which may not form glasses at all. These are of interest because of known or expected high melting temperatures. If they contain materials such as alumina, which is a glass network former under certain conditions, it is possible that they can be modified by small additions of other oxides to form useful glasses. Such compositions as X-802, X-803, X-825 are examples of compositions in this group.
3. Compositions known to give glasses which will be below those in Group 1 in temperature resistance, but which may nevertheless give useful information. For example, glasses in the series X-26A to X-36A were studied for two reasons:
   a. To get a comparison of the relative effects of calcia versus magnesia and alumina versus silica on temperature resistance.
   b. To establish approximately what performance might be expected from the most viscous glasses that might be formed in ordinary platinum alloy bushings by usual procedures.

The compositions evaluated may be further classified as being silicate based or non-silicate based.

The following considerations apply to the development of silicate based compositions. Both the fiber-forming behavior and the upper service temperature of a glass are determined largely by its viscosity-temperature relationship. Pure silica has what is described as a flat viscosity-temperature curve. By this is meant that a given change in temperature produces a relatively small change in viscosity as compared for instance, with "E" glass, which has a steep viscosity curve. As a result, the temperature required for forming fibers of pure silica is higher than that required for fiberizing "E" glass by an amount considerably greater than the increase in upper service temperature realized for the fibers.

There seems to be little probability that an additive can be found for silica which will raise the entire viscosity curve. All additives can be expected to lower the viscosity of silica in the high temperature region. What is sought, therefore, is an additive which will steepen the viscosity curve and cause it to cross that of the pure silica glass, and at as high a temperature as possible. Fibers could be produced from

such a glass more readily and at a lower temperature than from pure silica and they conceivably could actually withstand a higher temperature under load before yield occurs. Beryllium oxide seems likely to be the most effective additive to lower the fiber forming temperature of a glass without lowering its temperature resistance on the basis of observations of the effect of other oxides from Group II of the Periodic Table and from the results of earlier work on modifications of "E" glass containing this oxide.

Non-silicate based compositions conceivably could be found which would have either higher forming temperatures or higher service temperatures or both. They could be expected to have very steep viscosity curves and might have high melting temperatures if based on oxides with high melting points (e.g., Al_2O_3, TiO_2, ZrO_2).

For convenience in evaluating the results, the compositions are separated in Table II into the following groups:

1. SiO_2-Al_2O_3-ZrO_2
2. SiO_2-Al_2O_3-TiO_2
3. SiO_2-Al_2O_3-BaO
4. SiO_2-Al_2O_3-CaO-MgO
5. SiO_2-Al_2O_3-CaO
6. SiO_2-Al_2O_3-MgO
7. Al_2O_3-BaO
8. SiO_2-Al_2O_3-U_3O_8
9. SiO_2-Al_2O_3-ThO_2
10. SiO_2-Al_2O_3-Rare Earth Oxides
11. SiO_2-ZrO_2-M_xO_y
12. SiO_2-Al_2O_3-V_2O_5
13. SiO_2-Al_2O_3-Ta_2O_5
14. Ta_2O_5 base
15. SiO_2-Al_2O_3-Nb_2O_5
16. SiO_2-MnO_2-M_xO_y
17. P_2O_5 base
18. SiO_2-WO_3
19. ZrO_2 base
20. Miscellaneous - Hot stage results only
21. Miscellaneous - Run in one hole bushing

The groups listed above comprising three component-systems including Al_2O_3 also include those compositions in which the alumina content is zero. The symbol M_xO_y is used in some cases to indicate any of a number of oxides investigated as additives to the designated systems.

Screening Evaluation of Compositions Prior to Fiberization Trials

A rough approximation of forming temperatures, liquidus temperatures and fiberizability of experimental compositions was obtained by use of an iridium metal electrically heated strip used as a hot stage for a microscope. The metal was protected from excessive oxidation by an argon atmosphere. Observations were made through a water cooled colored glass filter. With this apparatus a very small amount of batch was tested. The approximate temperature required to melt all the batch was determined. The melted glass was then cooled and the rapidity of devitrification and approximate liquidus temperature were determined. The glass was then reheated above the liquidus temperature and a fiber pulled from the melt by means of a metal wire probe. From this test an estimate of the

probability of being able to fiberize the glass was made. Temperatures were measured with a Leeds and Northrup Model #8622 optical pyrometer sighted on the melt. They are reported without correction for emissivity, since there is no accurate way of estimating emissivity for all of the experimental compositions used.

Compositions were discarded if the batch had not melted at about 4000°F; if the melt seemed very fluid at lower temperatures, e.g., 3000°F; or if it devitrified before a viscosity could be reached at which it was possible to get some indication that fibers could be formed.

Production of Sample Quantities of Fibers

The preferred method of producing single fibers of ordinary glasses involves the use of pre-melted glass, which is introduced into a one hole bushing as cullet. A number of experiments were performed in an effort to produce cullet of experimental high temperature glasses for subsequent fiber-forming trials in bushings. Cullet of glasses X-798 and X-815 was obtained by use of iridium crucibles in an acetylene-oxygen crucible furnace. Several efforts were made to develop procedures for using crucibles with potentially higher service temperatures than iridium, but none was completely successful. Crucibles of graphite and thoria-coated graphite failed even though attempts were made to keep them in an inert atmosphere. Molybdenum crucibles in hydrogen showed some promise but were not dependable. The difficulty of obtaining suitable cullet was such that most fiber-forming tests were made on glass produced directly in the bushing from calcined batch. Batches were formulated from technical grade raw materials which were 200 mesh or finer when such materials were available. Reagent grade chemicals were used when necessary. The batches were weighed, mixed, and calcined at about 2600°F to remove volatiles which might have caused batch dusting or formation of bubbles during subsequent melting in the bushing.

Radiation pyrometers were used for controlling temperatures of the bushings, and optical pyrometers were used to read temperatures through silica glass windows in the sides of the bushing cases. Temperatures reported were not corrected for the emissivity of the metal, because of uncertainty regarding the effects of the condition of the metal surface and of the bushing construction on the amount of correction that should be applied. On the basis of rough calculations and of measurements made on one occasion with a Shawmeter, which is reported to give readings unaffected by emissivity, it is estimated that reported readings are low by 400 to 500°F. Maximum actual operating temperatures for these bushings appeared to be about 4000-4100°F. Bushing life at these temperatures was usually quite short. When temperatures were held one or two hundred degrees under the maximum, bushings could usually be operated for several weeks before repair or replacement was necessary.

Room temperature fiber strengths obtained on fibers produced with these bushings appeared in general to be about half those obtained with "E" glass formed from platinum bushings. The relatively poor glass quality obtained by melting batch directly in the bushing was felt to be partly responsible. However, very little improvement was noted when cullet collected in the form of beads from the bushing was re-melted. Fibers produced from "E" glass marbles run in one of the high temperature bushings were also only approximately half as strong as fibers produced by standard methods. It was found that "E" glass fibers having about 80 per cent of normal strengths could be produced by known proprietary variations in forming techniques, including cooling of the tip area by a platinum water cooler and a jet of argon. This technique was used subsequently with experimental compositions, and apparently was beneficial, although average room temperature strengths continued to be well below those considered normal for "E" glass.

It proved to be impractical to produce pure silica fibers from a bushing because of the high viscosity of silica even at high temperatures. A continuous redraw unit was built for possible use in redrawing special high temperature glasses from batch or cullet rods. Using this unit, silica fibers having a tensile strength of 270,000 psi at 2000°F were drawn from silica rods.

Qualitative Testing of Fibers for Temperature Resistance

Small bundles of fibers from the one hole bushing were cut from the drum upon which they were wound and placed in a muffle furnace at either 1600 or 1800°F for 30 minutes. At the end of that time, they were removed, cooled, and examined. If the fibers were still flexible and had some strength, they were returned for another 30 minutes to the muffle furnace. The temperature setting was increased 100°F each time, and testing was continued until the sample failed. This test gave a rough idea of the temperature limitation of the fibers and also showed the effect of somewhat extended time of exposure as compared with other tests. It also showed the nature of failure, which might be either by sintering or by loss of strength without deformation, presumably because of devitrification or other structural rearrangement.

Quantitative Testing of Fibers for Strength and Modulus

Whenever an experimental glass ran well enough in the one-hole bushing to produce suitable samples, tensile strength measurements were made. Untouched fibers were mounted in an apparatus in which a three inch span was broken in tension. Measurements were usually made at room temperature and at elevated temperatures. The elevated temperatures were attained by placing a small resistance furnace around one inch of the center portion of the fiber. A load-elongation diagram was plotted

on a recorder. These were examined for evidence of yield and the load at which yield occurred was recorded.

Modulus measurements at room temperature were made on a number of glasses. This was done on fibers by the sonic method. The density of the glass is required for making the calculation. This was measured on unannealed beads of glass from the one hole bushing. In some cases, it was not possible to get a bead free of seeds and/or devitrification. Consequently, neither density not modulus values reported should be regarded as better than a close approximation to actual values.

Production of Larger Samples

Attempts were made to prepare cullet of two experimental compositions in a pilot plant sized arc melting furnace of the type used to melt electrocast refractories. The objectives were to evaluate this type of equipment for larger scale production of cullet and to determine the quality of the cullet obtainable. X-815 glass was tried and performed so poorly that the experiment was discontinued. The glass did not become a good enough electrical conductor to work in the unit, even after the addition of a quantity of soda ash to the batch.

It has been demonstrated that a 12 filament strand of X-815 glass fibers can be drawn from a 12 orifice bushing.

Surface Treatments

A proprietary surface treatment for fibers was known to impart some additional resistance to temperature when applied to "E" glass or leached (Refrasil) fibers. An investigation of the effect of this surface treatment on the temperature resistance of discontinuous or wool type of fibers of several other compositions was made. The temperature resistance under no stress static conditions was increased by 150°F to 800°F as determined by the appearance of fibers after exposure in a muffle oven at various temperatures for 30 minutes. Composition has some effect on the degree of increase of temperature resistance, but some improvement was observed with all compositions tested.

The effect of this treatment on tensile strength of fibers at room temperature and at elevated temperatures has not been determined. Yarns or tapes seem to be the logical forms of fibers to test the treatment or to determine its effect from the standpoint of both temperature resistance and abrasion resistance at high temperatures.

Results

A total of 327 experimental batches was studied. Of these, 302 compositions were investigated on the hot stage microscope. Most of these compositions were unsatisfactory because they were too fluid to fiberize, devitrified at forming temperature, or were too refractory to melt properly at available bushing operating temperatures. Those which appeared promising were run in the one-hole bushing. Of the compositions studied, 79 were promising enough to attempt fiberization.

The results obtained are summarized in Table II. In this table, the compositions are separated into the 21 groups listed on Page 8 of this report. The following comments may be of use in interpreting information found in this table.

Glass Compositions

The compositions studied are reported in weight percentages. Percentages are reported to the nearest 0.1 per cent, and consequently do not always total 100.0 per cent. Most compositions contain a small amount of iron oxide which was introduced through the use of commercial grade raw materials. Since iron oxide is a flux, some compositions of interest, e.g., X-879 glass, were formulated from essentially iron free batch to eliminate this factor.

Iridium Strip Data

The observations made on the melting of batches on the iridium strip are also summarized in the table. The temperatures reported were taken with the Leeds and Northrup optical pyrometer sighted on the molten batch. These readings are low because corrections for emissivity were not made. Uncertainty regarding proper values for the correction factor made attempts to apply corrections rather useless.

One-Hole Bushing Temperatures

The temperature of the one-hole bushing was also measured optically. The instrument was sighted on the bushing wall through a silica window. It is estimated that the reported readings are low by 400° or 500°F. Correction factors were not applied because of some uncertainty regarding their accuracy.

Temperature Resistance

The table also records the refractoriness of the compositions tested. Bundles of fibers were heated in a muffle furnace for 30 minute intervals at increasingly higher temperatures. They were then removed from the furnace, allowed to cool, and judged qualitatively by feel as to strength. The purpose of this test is to show qualitatively the tendency of the fibers after exposure to high temperatures to sinter, devitrify, or undergo other structural rearrangements with time such as those which cause brittleness with silica fibers.

Tensile Strength Studies

The tensile strengths of the compositions studied are shown. Two values are usually given. The first is the average breaking stress, the other is the stress at which yield occurred when yield was observed.

Young's Modulus

The values of Young's modulus for the glasses investigated are also listed. In calculating these values, use was made of glass density measurements made on glass beads which were not annealed and which were often devitrified or contained seeds. Some of the values, therefore, are only close approximations. Measurement was by the sonic method, and was made on fibers.

Specific Gravity

Table II lists the specific gravities of the glasses studied. As pointed out above, the values are approximate. They were determined by the Archimedes method. The specific gravities were taken for the purpose of determining Young's modulus and because of interest in strength-to-weight ratios for glass reinforced plastics.

Comments Regarding Results

The relatively low room temperature fiber tensile strengths reported for all of the experimental glasses are probably a result of forming conditions, rather than an inherent property of the glasses. Two considerations lead to this conclusion: (1) in a series of glasses of differing composition, there is a tendency for fiber tensile strength to go up as the temperature required for fiber forming goes up and there is no apparent reason why all the high melting glasses in the present investigation should be exceptions; and (2) the particular forming equipment used tended to give low results with "E" glass also. It was demonstrated that changes could be made which improved strengths. There is no obvious reason why bushing modifications could not be made

which would make it possible to realize the expected high strengths for fibers of these glasses. Work with bushing modifications should be included in or be done concurrently with future programs since it seems probable that room temperature strengths could be significantly increased by bushing design changes, and possible that this would raise the strengths obtained at elevated temperatures also.

It will be noted that strength data are not available at all testing temperatures for all compositions. This may be true for either of two reasons: (1) If the first tests indicated that the glass was less interesting than previously tested glasses, fewer tests were run. (2) In some cases only a limited number of fibers were produced either because the glass ran so poorly or because it ran at such a high temperature that a minimum operating time was observed to protect the bushing. The intent of the testing program which yielded the data reported in Table II was primarily to enable the selection of a few of the most promising compositions for subsequent more careful evaluation and comparison.

In evaluating these data, particular attention was given to the temperature at which yield occurred. It was felt that this would tend to be independent of fiber quality and that it would be a good indication of the upper service temperature of a glass. The actual values of strength were found to be quite variable, depending on fiber diameter and forming conditions.

The final testing of the best compositions selected on the basis of the screening tests should include tensile strength measurements at all temperatures above 1000°F, since ultimate use may well be primarily in the 1000-1500°F range. Glass X-815 was selected as the most promising composition for further study, for the preparation of samples, etc., on the basis of the following considerations. It performed as well as any on the qualitative 30 minute tests on bundles of fibers; the first tests indicated that it was nearly as good as any in tensile strength at 1800°F, and that yield temperature was high; it formed very well, and at temperatures lower than many of the glasses of comparable value; it was among the highest in modulus of elasticity; and the batch was free of raw materials which might be undesirable because of limited availability, very high cost, toxicity, or radioactivity. Subsequent testing gave tensile strengths somewhat lower than those found initially and reported earlier. The later (and lower) results are probably more accurate and are reported in Tables I and II. Above 1800°F, yield was too great for valid testing.

Subsequent testing of the remainder of the most promising compositions may reveal that X-815 was not actually the best choice, but it seems unlikely that any will have properties vastly better than X-815.

Mention has been made of compositions which were not fiberized because melting temperatures measured on the hot strip exceeded the temperature limitation of the bushings. This suggests that compositions

still better than any tested may be available provided forming means can be devised. This may be true, but on the other hand, it may mean only that the compositions in question have high liquidi and that they would be too fluid to form after melting.

Conclusions

Fiberizable glass compositions have been found with properties considerably better than any presently commercially available fibers, although the target properties were not reached.

The value of these fibers and their performance in potential end uses have not yet been established.

Commercial scale production of such fibers appears feasible, but requires considerable development effort.

The probability of obtaining substantial improvements in glass properties over those of the best glasses developed in the present investigation seems low.

TABLE II - GLASS COMPOSITION AND PROPERTY DATA
GROUP 1 - SiO_2-Al_2O_3-ZrO_2 TERNARY

Glass Number	X-799	X-807	X-813	X-814	X-815
Composition					
SiO_2	40.0	87.5	69.9	69.9	69.9
Al_2O_3	40.0	.4	12.0	7.0	17.0
ZrO_2	20.0	11.9	18.0	23.0	13.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp. - °F	3150	Over 3300	Over 3170	3200	
Fiberizability					
Comments	Not quite clear			Devit. @ 3160°F	
OHB-Temperature-°F	3020		3460	3375	3100
Comments	Did not run Flooded or devit.	Did not run Flooded or devit.			
Fiber Condition 30 Minutes					
1800°F			Strong	Strong	Strong
1900			"	"	"
2000			"	"	"
2100			"	Less Strong	"
2200			Poor	Poor	"
2300					Poor

Tensile Strength - 10^3 psi						
	Av.	Yield	Av.	Yield	Av.	Yield
72°F					278	
1200	147					
1400					182	138
1500	119	100	241		182	126
1700					104	78
1800	90	56	193	172	110	93
2000	72	27				

Fiber Diameter 10^{-5} inch	90	43	34-44
Modulus, 10^6 psi	12.5	12.5	12.8
Specific Gravity	2.63	2.36-2.40	2.53

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 1 - SiO_2-Al_2O_3-ZrO_2 TERNARY

Glass Number	X-913	X-914	X-915	X-916	X-917
Composition					
SiO_2	94.5	90.5	89.9	79.9	64.9
Al_2O_3	0.4	0.4	5.0	5.0	5.0
ZrO_2	5.0	9.0	5.0	15.0	30.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp. - °F	3900+	3650	3700	3550	3800
Fiberizability	OK	OK	OK	OK	Fair
Comments	Incompletely melted	Very viscous	Viscous & seedy		Too fluid
OHB-Temperature-°F					3600
Comments					Incompletely melted
Fiber Condition 30 Minutes					
1800°F					*Strong
1900					"
2000					Fair
2100					Very poor
Tensile Strength 10^3 psi					Av. / Yield
1500°F					248
1800					146 / 80
Fiber Diameter 10^{-5} inch					46-66
Modulus, 10^6 psi					
Specific Gravity					

*Very coarse fibers

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 1 - SiO_2-Al_2O_3-ZrO_2 TERNARY

Glass Number	X-918	X-919	X-920	X-921	X-922
Composition					
SiO_2	84.9	74.9	59.9	79.9	59.9
Al_2O_3	10.0	10.0	10.0	15.0	15.0
ZrO_2	5.0	15.0	30.0	5.0	25.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3600	3450	3700	3520	3560
Fiberizability	OK	OK	Negative	OK	Negative
Comments		Viscous		Seedy	Devit.
OHB-Temperature-°F		3280		3320	
Comments					
Fiber Condition					
30 Minutes					
1800°F		Strong		Strong	
1900		"		"	
2000		"		"	
2100		"		Weak	
2200		Poor			
Tensile Strength					
10^3 psi				Av.	Yield
1500°F				241	238
1600		No yield		198	148
1800		Yield			144
Fiber Diameter					
10^{-5} inch		32		27-40	
Modulus, 10^6 psi		11.8		12.3	
Specific Gravity		2.53		2.49	

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 1 - SiO_2-Al_2O_3-ZrO_2 TERNARY

Glass Number	X-1074	X-1075	X-1076	X-1077	X-1078
Composition					
SiO_2	69.9	59.9	59.9	59.9	50.0
Al_2O_3	23.0	22.0	28.0	33.0	10.0
ZrO_2	7.0	18.0	12.0	7.0	40.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3270	3200	3160	3140	3620
Fiberizability	Fair	Possible	Seedy Possible @ 2960	Negative	Negative
Comments		Devit.		Too fluid or devit.	Too fluid or devit.
OHB-Temperature-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 1 - SiO_2-Al_2O_3-ZrO_2 TERNARY

Glass Number	X-1079	X-1080	X-1081	
Composition				
SiO_2	50.0	50.0	50.0	
Al_2O_3	20.0	30.0	40.0	
ZrO_2	30.0	20.0	10.0	
Fe_2O_3	0.1	0.1	0.1	
Iridium Strip Data				
Melting Temp.-°F	3300	3140	3100	
Fiberizability	Negative	Negative	Negative	
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	
OHB-Temperature-°F				
Comments				
Fiber Condition				
30 Minutes				
Tensile Strength				
10^3 psi				
Fiber Diameter				
10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II - GLASS COMPOSITION AND PROPERTY DATA
GROUP 2 - SiO_2-Al_2O_3-TiO_2 TERNARY

Glass Number	X-796	X-797	X-798	X-817	X-963
Composition					
SiO_2	73.4	69.4	69.9	52.9	94.5
Al_2O_3	25.7	29.6	12.0	45.4	0.4
TiO_2	0.7	0.8	18.0	1.2	5.0
Fe_2O_3	0.3	0.3	0.2	0.3	0.1
Na_2O				0.2	
Iridium Strip Data					
Melting Temp.-°F			3100	2920	3820
Fiberizability					Seedy
Comments			Glass black.		Negative Viscous
OHB-Temperature-°F	3410	3320	3010-3175		
Comments				Ran only when mixed with previous glass	
Fiber Condition 30 Minutes					
1600°F	Good	Good			
1800	Melted	Very weak	Very good	Strong	
1900			" "	"	
2000			" "	"	
2100			" "	"	
2200			Poor	"	
2300				Weak	
Tensile Strength			Av. Yield		
10^3 psi 72°F			272		
1800			161 128		
2000			59		
Fiber Diameter 10^{-5} inch			39		
Modulus, 10^6 psi			11.8		
Specific Gravity			2.43		

TABLE II - GLASS COMPOSITION AND PROPERTY DATA
GROUP 2 - SiO_2-Al_2O_3-TiO_2 TERNARY

Glass Number	X-964	X-965	X-1082	X-1083	X-1084
Composition					
SiO_2	89.5	84.6	79.9	69.9	69.9
Al_2O_3	0.4	0.3	10.0	7.0	20.0
TiO_2	10.0	14.9	10.0	23.0	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3820	3820	3300	3260	3240
	Not clear				
Fiberizability	OK	Negative	Difficult	Difficult	Negative
Comments	Viscous	Too fluid			
OHB-Temperature-°F	3570				
Comments	Needs higher temperature				
Fiber Condition					
30 Minutes					
1800°F	Slightly brittle				
1900	"	"			
2000	"	"			
2100	"	"			
2200	More brittle				
2300	Very weak				
Tensile Strength					
10^3 psi	Av.	Yield			
1500°F	99*				
1600	144				
1700	127	72			
1800	56*	26			
Fiber Diameter					
10^{-5} inch	71				
	*(120-130)				
Modulus, 10^6 psi					
Specific Gravity					

*Strengths at 1500 and 1800°F measured on the larger fibers.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 2 - SiO_2-Al_2O_3-TiO_2 TERNARY

Glass Number	X-1085	X-1086	X-1087	
Composition				
SiO_2	59.9	59.9	59.9	
Al_2O_3	10.0	20.0	30.0	
TiO_2	30.0	20.0	10.0	
Fe_2O_3	0.1	0.1	0.1	
Iridium Strip Data				
Melting Temp.-°F	3190	3140	3140	
Fiberizability	Negative Too fluid or devit.	Difficult Too fluid or devit.	Negative Too fluid or devit.	
OHB Temperature-°F				
Comments				
Fiber Condition 30 Minutes				
Tensile Strength 10^3 psi				
Fiber Diameter 10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 3 - SiO_2-Al_2O_3-BaO TERNARY

Glass Number	X-800	X-821	X-823	X-824	X-825
Composition					
SiO_2	45.9	30.0	10.0	20.0	30.0
Al_2O_3	0.2	59.5	49.5	44.0	38.5
BaO	53.9	10.5	40.5	36.0	31.5
Fe_2O_3	0.1	0.1			
Iridium Strip Data					
Melting Temp.-°F	2870	3375	3150	3180	3450
Fiberizability		Negative Could not quench clear	Possible Quenched clear*	Possible Quenched clear*	Possible Quenched clear*
OHB Temperature-°F					
Comments					Too fluid or devit.
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

***Fiberizable if viscosity and surface tension are of right order.**

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 3 - SiO_2-Al_2O_3-BaO TERNARY

Glass Number	X-923	X-924	X-925	X-926	X-927
Composition					
SiO_2	40.0	50.0	59.9	69.9	79.9
Al_2O_3	50.0	40.0	30.0	20.0	10.0
BaO	10.0	10.0	10.0	10.0	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3340-3400	3300	3460	3300	3440
Fiberizability	Negative	Negative	Possible	Possible	Possible
Comments	Devit.	Devit.	Liquidus high		
OHB Temperature-°F					3600
Comments					
Fiber Condition 30 Minutes					
1800°F					Brittle
1900					"
2000					Poor
2100					Very poor
Tensile Strength 10^3 psi					Av. / Yield
1200°F					223 /
1500					219 / 176
1900					124 / 66
Fiber Diameter 10^{-5} inch					38-40
Modulus, 10^6 psi					12.6
Specific Gravity					2.75

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 3 - SiO_2-Al_2O_3-BaO TERNARY

Glass Number	X-928	X-948	X-949	X-950	X-1130
Composition					
SiO_2	89.5	94.5	89.6	84.6	79.6
Al_2O_3	0.4	0.4	0.4	0.3	0.3
BaO	9.9	5.0	10.0	14.9	19.9
Fe_2O_3	0.1	0.1	0.1	0.1	0.2
Iridium Strip Data					
Melting Temp.-°F	3340	3160	3200	3170	3100
Fiberizability	OK	OK @ 33-3400°	OK @ 33-3400°	OK @ 3420°	OK
Comments					
OHB Temperature-°F		3360		2950	
Comments					
Fiber Condition 30 Minutes					
1800°F		Good		Strong	
1900		Very poor		"	
2000				"	
2100				"	
2200				"	
2300				Very poor	
Tensile Strength					
10^3 psi		Av. Yield		Av. Yield	
1200°F		263		142 103	
1300		253 113		163 115	
1500		225 80		88 55	
Fiber Diameter 10^{-5} inch		32		36	
Modulus, 10^6 psi		10.6		11.4	
Specific Gravity		2.4		2.81	

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 3 - SiO_2-Al_2O_3-BaO TERNARY

Glass Number	X-1131	X-1132	X-1144	X-1145	
Composition					
SiO_2	74.7	69.7	68.1	63.5	
Al_2O_3	0.3	0.3	9.1	9.1	
BaO	24.9	29.9	22.7	27.3	
Fe_2O_3	0.1	0.1	0.1	0.1	
Iridium Strip Data					
Melting Temp.-°F	2925	2930	3050	2920	
				Seedy	
Fiberizability	OK	Possible but devit.	OK @ 3150-3200°	OK @ 3150°	
OHB Temperature-°F					
Comments					
Fiber Condition					
30 Minutes					
1600°F				Slightly brittle	
1700				Brittle	
1800			Weak	Very weak	
Tensile Strength					
10^3 psi			Av. Yield	Av. Yield	
900°F			245 (259)	316 260	
1000				254 (269)	
1100			206 192		
1200			177 151	222 204	
1400			Yields	25	
1500				Yields	
Fiber Diameter					
10^{-5} inch			34	37.5	
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 4 - SiO_2-Al_2O_3-CaO-MgO QUATERNARY

Glass Number	X-31A	X-36A	X-792	
Composition				
SiO_2	59.6	59.5	59.4	
Al_2O_3	19.9	24.8	27.2	
CaO	5.0	5.0	2.5	
MgO	14.9	9.9	9.9	
Fe_2O_3	0.3	0.2	0.3	
TiO_2	0.5	0.6	0.7	
Iridium Strip Data				
Melting Temp.-°F				
Fiberizability				
Comments				
OHB Temperature-°F	2495	2650	2690	
Comments				
Fiber Condition				
30 Minutes				
1600°F	Good	Good	Good	
1700	Melted	Very weak	"	
1800		Melted	Melted	
Tensile Strength 10^3 psi				
Fiber Diameter 10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 5 - SiO_2-Al_2O_3-CaO TERNARY

Glass Number	X-794	X-795	X-801	X-868	X-869
Composition					
SiO_2	65.4	69.5	59.8	69.9	64.9
Al_2O_3	22.8	24.4	0.2	19.5	23.0
CaO	10.8	5.2	39.8	10.5	12.0
MgO	0.1				
Fe_2O_3	0.3	0.3	0.1	0.1	0.1
TiO_2	0.6	0.6			
Iridium Strip Data					
Melting Temp.-°F			2650	3600	3150
Fiberizability				Possible	Possible
Comments					
OHB Temperature-°F	3340	2850-3125			
Comments					
Fiber Condition					
30 Minutes					
1600°F	Good	Good			
1800	Melted	Very weak			
Tensile Strength					
10^3 psi		Av.			
72°F		332			
Fiber Diameter					
10^{-5} inch		33			
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 5 - SiO_2-Al_2O_3-CaO TERNARY

Glass Number	X-870	X-871	X-872	X-873	X-894
Composition					
SiO_2	59.9	50.0	40.0	35.0	66.0
Al_2O_3	20.0	22.0	28.0	34.0	23.0
CaO	20.0	28.0	32.0	31.0	11.0
Fe_2O_3	0.1	0.1	0.1	0.1	
Iridium Strip Data					
Melting Temp.-°F	2850	2370	2400	2610	
Fiberizability	Possible	Questionable	Possible	Negative	
Comments				Devit.	
OHB Temperature-°F	2800	2800			3140
Comments		Flooded			
Fiber Condition					
30 Minutes					
1600°F					Very good
1800					Poor
Tensile Strength					
10^3 psi	Av.				Av.
72°F	475				442
Fiber Diameter					
10^{-5} inch					30
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 5 - SiO_2-Al_2O_3-CaO TERNARY

Glass Number	X-895	X-896	X-947	X-968	X-969
Composition					
SiO_2	76.0	76.0	55.0	55.0	55.0
Al_2O_3	17.0	19.0	21.0	25.0	20.0
CaO	7.0	5.0	24.0	20.0	25.0
Fe_2O_3			0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F			2550 Seedy	2700	2700
Fiberizability			OK	Possible below 2700	Possible below 2700
Comments					
OHB Temp.-°F	3325	3360			2650
Comments					
Fiber Condition					
30 Minutes					
1600°F	Very good	Very good			
1800	Poor	Fair			
Tensile Strength					
10^3 psi					
72°F					Av. 448
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 5 - SiO_2-Al_2O_3-CaO TERNARY

Glass Number	X-996	
Composition		
SiO_2	75.0	
Al_2O_3	10.0	
Ca O	15.0	
Iridium Strip Data		
Melting Temp.-°F		
Fiberizability		
Comments		
OHB Temp.-°F	2900	
Comments	Ran well	
Fiber Condition		
30 Minutes		
Tensile Strength		
10^3 psi	Av.	
72°F	404	
Fiber Diameter		
10^{-5} inch	39	
Modulus, 10^6 psi		
Specific Gravity		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 6 - SiO_2-Al_2O_3-MgO TERNARY

Glass Number	X-806	X-832	X-835	X-838	X-897
Composition					
SiO_2	64.7	5.0	20.0	55.4	77.5
Al_2O_3	0.3	87.4	73.6	15.0	17.4
MgO	34.9	7.6	6.4	29.6	5.1
Fe_2O_3	0.1			0.1	
Iridium Strip Data					
Melting Temp.-°F	2700	3165	2950	2600	
Fiberizability	Too fluid or devit.	Negative Devit.	Negative	Possible Too fluid	
Comments					
OHB TEMP.-°F					3500
Comments					
Fiber Condition					
30 Minutes					
1600°F					Very good
1800					" "
1900					Brittle
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 6 - SiO_2-Al_2O_3-MgO TERNARY

Glass Number	X-994	X-995	X-997	X-1031	X-1032
Composition					
SiO_2	65.0	70.0	75.0	5.0	5.0
Al_2O_3	25.0	25.0	10.0	90.0	85.0
MgO	10.0	5.0	15.0	5.0	10.0
Iridium Strip Data					
Melting Temp.-°F				3460	3540
Fiberizability				Negative	Negative
Comments				Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F	3130	2900	2850		
Comments	Devit.				
Fiber Condition					
30 Minutes					
1800°F	Intact but sintered.				
2000	Intact but sintered.				
Tensile Strength					
10^3 psi	Av.	Av.	Av.		
72°F	635	479	443		
1200	217*				
Fiber Diameter					
10^{-5} inch	40	42	35		
Modulus, 10^6 psi					
Specific Gravity					

*Average of six breaks - consider only as indication.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 6 - SiO_2-Al_2O_3-MgO TERNARY

Glass Number	X-1033	X-1034	X-1035	X-1036	X-1037
Composition					
SiO_2	5.0	5.0	5.0	5.0	10.0
Al_2O_3	75.0	65.0	55.0	45.0	85.0
MgO	20.0	30.0	40.0	50.0	5.0
Iridium Strip Data					
Melting Temp.-°F	4000	3680	3630	3585	3435
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Not melted	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 6 - SiO_2-Al_2O_3-MgO TERNARY

Glass Number	X-1038	X-1039	X-1040	X-1041	X-1042
Composition					
SiO_2	10.0	10.0	10.0	10.0	10.0
Al_2O_3	80.0	70.0	60.0	50.0	40.0
MgO	10.0	20.0	30.0	40.0	50.0
Iridium Strip Data					
Melting Temp.-°F	3320	3400	3460	3480	3350
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 6 - SiO_2-Al_2O_3-MgO TERNARY

Glass Number	X-1043	X-1044	X-1045	X-1046	X-1047
Composition					
SiO_2	15.0	15.0	15.0	15.0	15.0
Al_2O_3	80.0	70.0	60 0	50.0	40.0
MgO	5.0	15.0	25.0	35.0	45.0
Iridium Strip Data					
Melting Temp.-°F	3420	3380	3380	3380	3420
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 6 - SiO_2-Al_2O_3-MgO TERNARY

Glass Number	X-1148	X-1150	X-26A	X-30A	X-35A
Composition					
SiO_2	64.9	79.9	59.6	59.6	59.4
Al_2O_3	31.0	12.0	19.9	24.8	29.7
MgO	4.0	8.0	19.9	14.9	9.9
Fe_2O_3	0.1	0.1	0.2	0.3	0.3
TiO_2			0.5	0.6	0.8
Iridium Strip Data					
Melting Temp.-°F					
Fiberizability					
Comments					
OHB Temp.-°F	3000	3300	2685	2700	2890
Comments					
Fiber Condition					
30 Minutes					
1600°F			Strong	Strong	Strong
1700			Sintered	Very weak	Very weak
1800	Strong	Strong	Melted	Sintered	Melted
1900	"	"			
2000	Fair	"			
2100	Very weak	Fair			
2200		Very weak			
Tensile Strength					
10^3 psi		Av. Yield		Av.	
72°F		505		494	
1500		110			
Fiber Diameter					
10^{-5} inch		55		40	
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 7 - Al_2O_3-BaO BINARY

Glass Number	X-802	X-803	X-804	X-805	X-818
Composition					
Al_2O_3	45.0	55.0	72.0	92.0	85.0
BaO	55.0	45.0	28.0	8.0	15.0
Iridium Strip Data					
Melting Temp.-°F	3200		3000	3020	3520
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments		Could not melt		Devit. @ 2920	Liquidus high
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 8 - SiO_2-Al_2O_3-U_3O_8 TERNARY

Glass Number	X-875	X-876	X-877	X-878	X-879
Composition					
SiO_2	49.9	59.8	69.7	79.6	89.5
Al_2O_3	0.2	0.2	0.3	0.3	0.4
U_3O_8	49.9	39.9	29.9	19.9	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	4000	3900	Over 4000	Over 4000	4000
Fiberizability	Negative	OK			OK
Comments	Devit.	Viscous	Too viscous		
OHB Temp.-°F		3450-3550		3560	3520
Comments		Too viscous to pull well		Too viscous to pull well	
Fiber Condition					
30 Minutes					
1800°F				Strong	Strong
1900				"	"
2000				"	"
2100				Weak	"
2200					"
Tensile Strength					
10^3 psi				Av. Yield	Av. Yield
1200°F				41.5	
1500				52 43	
1700				58 26	
1800				53 40	210 137
2000				76 40	173 106
2200				41.5 35	
Fiber Diameter					
10^{-5} inch				110	29-32
Modulus, 10^6 psi				11.2	11.3
Specific Gravity				2.64	2.4

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 8 - SiO_2-Al_2O_3-U_3O_8 TERNARY

Glass Number	X-879A	X-880	X-881	X-882	X-883
Composition					
SiO_2	90.0	50.0	59.9	69.9	79.9
Al_2O_3	----	10.0	10.0	10.0	10.0
U_3O_8	10.0	40.0	30.0	20.0	10.0
Fe_2O_3	----	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F		3300	3500	3620	3450
Fiberizability		OK	OK	Favorable Liquidus high	Favorable but viscous
OHB Temp.-°F	3650		2905		
Comments					
Fiber Condition					
30 Minutes					
1800°F	Strong		Strong		
1900	Poor		"		
2000			"		
2100			"		
2200			"		
2300			Weak		
Tensile Strength					
10^3 psi	Av. Yield		Av. Yield		
1500°F	64		271 252		
1800	121 111		156 98		
2000	85 39				
2200	Yields				
Fiber Diameter					
10^{-5} inch	120		40-41		
Modulus, 10^6 psi	11.7		12.2		
Specific Gravity	2.30		3.0		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 8 - SiO_2-Al_2O_3-U_3O_8 TERNARY

Glass Number	X-884	X-885	X-886	X-887	X-888
Composition					
SiO_2	50.0	59.9	69.9	50.0	59.9
Al_2O_3	20.0	20.0	20.0	30.0	30.0
U_3O_8	30.0	20.0	10.0	20.0	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3250	3200	3810	3300	3350
Fiberizability	Possible, but devit.	Possible Fluid		Negative	Negative
Comments					High liquidus
OHB Temp.-°F			2870		
Comments					
Fiber Condition					
30 Minutes					
1800°F			Strong		
1900			"		
2000			"		
2100			"		
2200			"		
2300			Poor		
Tensile Strength					
10^3 psi			Av.	Yield	
1500°F			195	174	
1800			45	22	
Fiber Diameter					
10^{-5} inch			45-59		
Modulus, 10^6 psi			12.0		
Specific Gravity			2.55-2.56		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 8 - SiO_2-Al_2O_3-U_3O_8 TERNARY

Glass Number	X-889	X-1022	
Composition			
SiO_2	50.0	89.5	
Al_2O_3	40.0	0.4	
U_3O_8	10.0	7.0	
Fe_2O_3	0.1	0.1	
MnO_2		3.0	
Iridium Strip Data			
Melting Temp.-°F	3400	3600	
Fiberizability	Negative	OK @ 3900	
Comments	Too fluid or devit.		
OHB Temp.-°F			
Comments			
Fiber Condition			
30 Minutes			
Tensile Strength			
10^3 psi			
Fiber Diameter			
10^{-5} inch			
Modulus, 10^6 psi			
Specific Gravity			

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 9 - SiO_2-Al_2O_3-ThO_2 TERNARY

Glass Number	X-890	X-898	X-899	X-900	X-901
Composition					
SiO_2	69.9	49.9	59.8	69.7	79.6
Al_2O_3	12.0	0.2	0.2	0.3	0.3
ThO_2	18.0	49.9	39.9	29.9	19.9
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3240	3950	4000	4000	4000
Fiberizability	Possible	Negative	Negative	Not melted	OK
Comments	Liquidus high	Liquidus high	Liquidus high		Viscous
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-3} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 9 - SiO_2-Al_2O_3-ThO_2 TERNARY

Glass Number	X-902	X-903	X-904	X-905	X-906
Composition					
SiO_2	89.5	50.0	59.9	69.9	79.9
Al_2O_3	0.4	10.0	10.0	10.0	10.0
ThO_2	10.0	40.0	30.0	20.0	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	4000	3800	3460	3300	3600
Fiberizability		Negative	Possible	OK	OK
Comments		Devit.	Liquidus high	Viscous	Viscous
OHB Temp.-°F	3540		3120	3215	3750
Comments					
Fiber Condition					
30 Minutes					
1800°F	Strong		Strong	Strong	Strong
1900	"		"	"	"
2000	"		"	"	Weak
2100	Weak		Fair	Weak	
2200	Very poor		Poor		
Tensile Strength					
10^3 psi	Av. Yield		Av. Yield	Av. Yield	Av. Yield
1200°F	266		273	304	
1500	227 Some yield		245 204	249 192	
1800	106		58	68	93
1900					78 47
2000					42
Fiber Diameter					
10^{-5} inch	22-26		40	40	180
Modulus, 10^6 psi				11.7	
Specific Gravity			2.95	2.75	2.49

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 9 - SiO_2-Al_2O_3-ThO_2 TERNARY

Glass Number	X-907	X-908	X-909	X-910	X-911
Composition					
SiO_2	50.0	59.9	69.9	50.0	59.9
Al_2O_3	20.0	20.0	20.0	30.0	30.0
ThO_2	30.0	20.0	10.0	20.0	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3200	3300	3260	2120	3400
Fiberizability	Poor	OK	Poor	Negative	Negative
Comments	Liquidus high	Fluid		Too fluid	Too fluid
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 9 - SiO_2-Al_2O_3-ThO_2 TERNARY

Glass Number	X-912	X-1021	X-1029	
Composition				
SiO_2	50.0	89.5	78.9	
Al_2O_3	40.0	0.4	10.0	
ThO_2	10.0	7.0	10.0	
Fe_2O_3	0.1	0.1	0.1	
MnO_2		3.0	1.0	
Iridium Strip Data				
Melting Temp.-°F	3400	3600	34-3500	
Fiberizability	Negative	OK	OK @ 3500	
Comments	Too fluid			
OHB Temp.-°F				
Comments				
Fiber Condition				
30 Minutes				
Tensile Strength				
10^3 psi				
Fiber Diameter				
10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 10 - SiO_2-Al_2O_3-RARE EARTH OXIDES

Glass Number	X-848	X-851	X-853	X-854	X-892
Composition					
SiO_2		30.0	50.0	60.0	79.9
Al_2O_3	60.0	42.0	30.0	24.0	10.0
Fe_2O_3			0.1	0.1	0.1
CeO_2	40.0	28.0	20.0	16.0	10.0
Iridium Strip Data					
Melting Temp.-°F	3320	3150	3100	3050	3400
Fiberizability	Negative	Negative	Negative	Possible?	Possible
Comments					Viscous
OHB Temp.-°F					3440
Comments					
Fiber Condition					
30 Minutes					
1800°F					Strong
1900					"
2000					Weak
2100					"
Tensile Strength					
10^3 psi					Av. / Yield
1200°F					272
1500					244 / 181
1800					55
Fiber Diameter					
10^{-5} inch					46
Modulus, 10^6 psi					10.5
Specific Gravity					2.45-2.47

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 10 - SiO_2-Al_2O_3-RARE EARTH OXIDES

Glass Number	X-933	X-934	X-935	X-936	X-937
Composition					
SiO_2	94.5	89.5	84.6	79.6	74.7
Al_2O_3	0.4	0.4	0.3	0.3	0.3
La_2O_3	5.0	10.0	14.9	19.9	24.9
Fe_2O_3	0.1	0.1	0.1	0.3	0.1
Iridium Strip Data					
Melting Temp.-°F	3320	3460	3460	3640	3540
Fiberizability	Possible** @ 3800	Possible** @ 3800	Possible** @ 3800	Possible** @ 3800	Possible @ 3700
Comments	Devit.	Devit.	Devit.	Devit.	Devit.
OHB Temp.-°F				3560	
Comments				Required higher temp.	
Fiber Condition					
30 Minutes					
1800°F				Good*	
1900				"	
2000				Fair	
2100				Weaker	
2200				Brittle	
2300				Very poor	
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

*Very coarse fibers
**Fibers contained crystals indicating liquidus close to fiber forming temperature.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 10 - SiO_2-Al_2O_3-RARE EARTH OXIDES

Glass Number	X-938	X-939	X-940	X-941	X-942
Composition					
SiO_2	94.6	89.5	84.6	79.6	74.7
Al_2O_3	0.4	0.4	0.3	0.3	0.3
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Mixed Rare Earth Oxides	5.0	10.0	14.9	19.9	24.9
Iridium Strip Data					
Melting Temp.-°F	3360	3380	3300	3400	3400
Fiberizability	Possible @ higher temp.	Pulled @ 3950	Pulled* @ 3950 Devit.	Pulled* @ 3950 Devit.	Pulled @ 3950
Comments					
OHB Temp.-°F		2900-3300			
Comments					
Fiber Condition					
30 Minutes					
1800°F		Good			
1900		Very weak			
Tensile Strength					
10^3 psi		Av.	Yield		
1200°F		174			
1500		121	97		
1600		77	65		
1700			30		
Fiber Diameter					
10^{-5} inch		37-51			
Modulus, 10^6 psi		12.3			
Specific Gravity		2.78			

*Fibers contained crystalline material indicating liquidus close to fiber forming temperature.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 10 - SiO_2-Al_2O_3-RARE EARTH OXIDES

Glass Number	X-1003	X-1009	X-1010	X-1023	X-1024
Composition					
SiO_2	69.7	84.9	79.9	89.5	89.5
Al_2O_3	0.3	5.0	10.0	0.4	0.4
La_2O_3		10.0	10.0		7.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
CeO_2				7.0	
MnO_2	29.9			3.0	3.0
Iridium Strip Data					
Melting Temp.-°F	3800	3500	3420	3760	3565
Fiberizability	Pulled* @ 3720 Devit.	OK Liquidus high	OK, but viscous	OK Viscous	OK Viscous
Comments					
OHB Temp.-°F		31-3500			
Comments		Ran well			
Fiber Condition					
30 Minutes					
1800°F		Strong			
1900		"			
2000		"			
2100		"			
2200		Very weak			
Tensile Strength					
10^3 psi		Av.	Yield		
1200°F		298			
1400		377	336		
1600		299	260		
1800			77		
Fiber Diameter					
10^{-5} inch		27			
Modulus, 10^6 psi		9.8			
Specific Gravity		2.43			

*Fibers contained crystalline material indicating liquidus close to fiber forming temperature.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP II - SiO_2-ZrO_2-M_xO_y TERNARY

Glass Number	X-867	X-931	X-932	X-943	X-944
Composition					
SiO_2	69.8	79.6	89.5	69.9	69.7
Al_2O_3	0.3	0.3	0.4	3.5	0.3
ZrO_2	15.0	10.0	5.0	23.0	22.9
ThO_2	15.0	10.0	5.0		
La_2O_3				3.5	7.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	Could not melt	3520	3600	3850	3850
Fiberizability		OK	OK	Possible @ 3100	Possible @ 3100
Comments		Viscous	Viscous & seedy	Devit.	Devit.
OHB Temp.-°F		3560	3600		
Comments			Requires higher temp.		
Fiber Condition					
30 Minutes					
1800°F		Strong			
1900		"			
2000		"			
2100		"			
2200		"			
2300		Weak			
Tensile Strength					
10^3 psi		Av. Yield			
1400°F		215 175			
1500		195 155			
Fiber Diameter					
10^{-5} inch		55			
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 11 - SiO_2-ZrO_2-M_xO_y TERNARY

Glass Number	X-945	X-946	X-974	X-975	X-976
Composition					
SiO_2	69.2	69.7	89.5	84.6	84.6
Al_2O_3	0.3	0.3	0.4	0.3	0.3
ZrO_2	19.9	14.9	5.0	5.0	10.0
La_2O_3	10.0	14.9			
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
TiO_2			5.0	10.0	5.0
Iridium Strip Data					
Melting Temp.-°F	3850	3560	3760	4000	3600
Fiberizability	Possible*	Difficult Below 3560	Possible, too viscous @ 3950	Possible	Possible @ 4000
Comments	Devit.			Not completely melted	Viscous
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

*Fibers contained crystalline material - liquidus close to fiber forming temperature. Glass extensible but poor possibility of fiberizing.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 11 - SiO_2-ZrO_2-M_xO_y TERNARY

Glass Number	X-977	X-978	X-979	X-980	X-981
Composition					
SiO_2	79.6	79.6	79.6	69.7	69.7
Al_2O_3	0.3	0.3	0.3	0.3	0.3
ZrO_2	5.0	10.0	14.9	19.9	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
TiO_2	14.9	10.0	5.0	10.0	19.9
Iridium Strip Data					
Melting Temp.-°F	3600	3200	3700	3700	3750
Fiberizability	Possible @ 3750-3800	OK @ 3350	OK	Fair	OK
Comments				Fluid	Viscous
OHB Temp.-°F	3560		3540		
Comments					
Fiber Condition					
30 Minutes					
1800°F	Strong		Strong		
1900	Brittle		"		
2000	"		"		
2100	"		"		
2200	"		"		
2300	Very brittle		Weak		
Tensile Strength					
10^3 psi	Av.	Yield	Av.	Yield	
1500°F	100		195		
1600			174	141	
1700			165	103	
1800	92		97	55	
1900	92	43			
2000	29	14			
Fiber Diameter					
10^{-5} inch	83		37		
Modulus, 10^6 psi			9.8 approx.		
Specific Gravity			2.49		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 12 - SiO_2-Al_2O_3-V_2O_5 TERNARY

Glass Number	X-970	X-983	X-984	X-998	X-999
Composition					
SiO_2	84.6	94.5	89.5	87.9	87.6
Al_2O_3	0.3	0.4	0.4	2.0	0.4
V_2O_5	14.9	5.0	10.0	10.0	10.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Li_2O					2.0
Iridium Strip Data					
Melting Temp.-°F	4040	3950	4000	3520	3460
Fiberizability	Too viscous	Too viscous	OK	OK @ 3570	OK @ 3500
Comments	Not clear	Not clear	Not clear		
OHB Temp.-°F				3640	
Comments					
Fiber Condition					
30 Minutes					
1800°F				Strong	
1900				Poor	
2000				"	
2100				"	
2200				Very weak	
Tensile Strength					
10^3 psi				Av. Yield	
1500°F				295	
1800				116 70	
2000				Yields	
Fiber Diameter					
10^{-5} inch				37-80	
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 12 - SiO_2-Al_2O_3-V_2O_5 TERNARY

Glass Number	X-1000	X-1065		
Composition				
SiO_2	79.9	87.6		
Al_2O_3	5.0	0.4		
V_2O_5	15.0	10.0		
Fe_2O_3	0.1	0.1		
MnO_2		2.0		
Iridium Strip Data				
Melting Temp.-°F	3460	3400		
Fiberizability	OK	OK		
Comments				
OHB Temp.-°F				
Comments				
Fiber Condition				
30 Minutes				
Tensile Strength 10^3 psi				
Fiber Diameter 10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 13 - SiO_2-Al_2O_3-Ta_2O_5 TERNARY

Glass Number	X-988	X-989	X-990	X-1012	X-1018
Composition					
SiO_2	94.5	89.5	84.6	79.9	89.5
Al_2O_3	0.4	0.4	0.3	5.0	0.4
Ta_2O_5	5.0	10.0	14.9	15.0	7.0
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
MnO_2					3.0
Iridium Strip Data					
Melting Temp.-°F	3750 Seedy	3750 Seedy	3750	3700	3100
Fiberizability	Negative	Negative	Negative	OK	OK at higher temp.
Comments	Too viscous	Too viscous	Too viscous		
OHB Temp.-°F					3520
Comments				OHB burned out	
Fiber Condition					
30 Minutes					
1800°F				Very good	Good
1900				Good	"
2000				Fair	"
2100				Poor	"
2200				Weak	Very poor
2300				Very weak	
Tensile Strength					
10^3 psi					Av. / Yield
1500°F					174 / 151
1600					170 / 152
1700					107 / 99
Fiber Diameter					
10^{-5} inch					52
Modulus, 10^6 psi					
Specific Gravity					2.47

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 13 - SiO_2-Al_2O_3-Ta_2O_5 TERNARY

Glass Number	X-1061	X-1062	X-1063	X-1070	X-1071
Composition					
SiO_2	84.6	79.6	74.7	79.7	74.7
Al_2O_3	0.3	0.3	0.3	0.3	0.3
Ta_2O_5	11.9	16.9	22.9	19.9	24.9
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
MnO_2	3.0	3.0	3.0		
Iridium Strip Data					
Melting Temp.-°F	3560	3400	3520	3720	3480
Fiberizability	OK	OK	Poor	OK, but viscous	OK seedy
Comments					
OHB Temp.-°F		3535			
Comments					
Fiber Condition					
30 Minutes					
1800°F		Good			
1900		"			
2000		Very brittle			
Tensile Strength					
10^3 psi		Av. Yield			
1500°F		213			
1700		178			
1800		217 181			
2000		44 (46)			
Fiber Diameter					
10^{-5} inch		33-49			
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 13 - SiO_2-Al_2O_3-Ta_2O_5 TERNARY

Glass Number	X-1072	X-1073	X-1088	X-1089	X-1090
Composition					
SiO_2	69.7	64.8	89.9	79.9	69.9
Al_2O_3	0.3	0.3	5.0	10.0	15.0
Ta_2O_5	29.9	34.9	5.0	10.0	15.0
Fe_2O_3	0.1	0.1	0.2	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3340	3380	3850	3320	3300
Fiberizability	OK,	OK,	OK,	OK	OK
Comments	Seedy	Seedy	Viscous	Viscous	
OHB Temp.-°F				3540	3360
Comments					
Fiber Condition					
30 Minutes					
1800°F				Strong	Strong
1900				"	Fair
2000				Very weak	Brittle
2100				Sintered	Very weak
Tensile Strength					
10^3 psi				Av. Yield	Av. Yield
1200°F					158 (185)
1300				203 178	198 (210)
1400				220 198	
1500				275 241	122 87
1600				163 133	65 49
1700					22
Fiber Diameter					
10^{-5} inch				33-49	37-51
Modulus, 10^6 psi					
Specific Gravity					2.58

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 13 - SiO_2-Al_2O_3-Ta_2O_5 TERNARY

Glass Number	X-1094	X-1095	X-1096	X-1102	X-1103
Composition					
SiO_2	59.8	54.8	49.9	44.9	39.9
Al_2O_3	0.2	0.2	0.2	0.2	0.2
Ta_2O_5	39.9	44.9	49.9	54.9	59.9
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3600, Seedy	3600, Seedy	3520, Seedy	3300	3220
Fiberizability	OK @ 3900	OK	OK	OK, but devit.	OK, but devit.
Comments					
OHB Temp.-°F			3000-3400		
Comments			Ran well		
Fiber Condition					
30 Minutes					
1800°F			Strong		
1900			"		
2000			"		
2100			"		
2200			"		
2300			Very weak		
Tensile Strength					
10^3 psi			Av.	Yield	
1300°F			180		
1400			186	176	
1500			105	93	
1800			66	47	
Fiber Diameter					
10^{-5} inch			55-59		
Modulus, 10^6 psi			13.5		
Specific Gravity			3.2 (devit.)		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 13 - SiO_2-Al_2O_3-Ta_2O_5 TERNARY

Glass Number	X-1104	X-1173	X-1174	X-1175	
Composition					
SiO_2	34.9	5.0	10.0	15.0	
Al_2O_3	0.1				
Ta_2O_5	64.9	95.0	90.0	90.0	
Fe_2O_3	0.1				
Iridium Strip Data					
Melting Temp.-°F	3320	3080	3100	3200	
Fiberizability	Negative	Negative	Negative	Negative	
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 14 - Ta_2O_5

Glass Number	X-1146	X-1160	X-1161	X-1162	X-1163
Composition					
Al_2O_3		5.0	10.0	15.0	
Ta_2O_5	100.0	95.0	90.0	85.0	95.0
ZrO_2					5.0
Iridium Strip Data					
Melting Temp.-°F		3240	3000	2980	3300
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 14 - Ta_2O_5

Glass Number	X-1164	X-1165	X-1166	X-1167	X-1168
Composition					
Ta_2O_5	90.0	85.0	95.0	90.0	85.0
ZrO_2	10.0	15.0			
CaO			5.0	10.0	15.0
Iridium Strip Data					
Melting Temp.-°F	3360	3300	3160	3260	3400
Fiberizability	Negative Too fluid or devit.	Negative Too fluid or devit.	Negative Too fluid or devit.	Negative Too fluid or devit.	Negative Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 14 - Ta_2O_5

Glass Number	X-1170	X-1171	X-1172	
Composition				
Ta_2O_5	95.0	90.0	85.0	
MnO_2	5.0	10.0	15.0	
Iridium Strip Data				
Melting Temp.-°F	3500	3000	2980	
Fiberizability	Negative	Negative	Negative	
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	
OHB Temp.-°F				
Comments				
Fiber Condition 30 Minutes				
Tensile Strength 10^3 psi				
Fiber Diameter 10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II - GLASS COMPOSITION AND PROPERTY DATA
GROUP 15 - SiO_2-Al_2O_3-Nb_2O_5 TERNARY

Glass Number	X-991	X-992	X-993	X-1020	X-1066
Composition					
SiO_2	94.5	89.5	84.6	89.5	79.7
Al_2O_3	0.4	0.4	0.3	0.4	0.3
Nb_2O_5	5.0	10.0	14.9	7.0	19.9
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
MnO_2				3.0	
Iridium Strip Data					
Melting Temp.-°F	3900	3900	3900	3780	3520
Fiberizability	OK	OK	OK	OK	Segregation of batch?
Comments	Viscous	Viscous			
OHB Temp.-°F			3600	3550	
Comments			Too viscous to run well		
Fiber Condition					
30 Minutes					
1800°F			*Slightly brittle	Good	
1900			"	"	
2000			More	"	
2100			"	"	
2200			"	"	Very weak
2300			Very	"	
Tensile Strength					
10^3 psi				Av.	Yield
1300°F				310	
1400				325	
1500				194	(240)
1600				69	(172)
1700				60	
Fiber Diameter					
10^{-5} inch				35-36	
Modulus, 10^6 psi					
Specific Gravity					

*Fibers coarse and possibly mixed with previous glass.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 15 - SiO_2-Al_2O_3-Nb_2O_5 TERNARY

Glass Number	X-1067	X-1068	X-1069	X-1091	X-1091
Composition					
SiO_2	74.7	69.7	64.8	89.9	
Al_2O_3	0.3	0.3	0.3	5.0	
Nb_2O_5	24.9	29.9	34.9	5.0	
Fe_2O_3	0.1	0.1	0.1	0.2	
Iridium Strip Data					
Melting Temp.-°F	3560	3240	3440	3650	
Fiberizability	Difficult	Viscous	Fair	OK	
Comments					
OHB Temp.-°F				3560	
Comments				Viscous	
Fiber Condition					
30 Minutes					
1800°F			Good	Good	
1900			Brittle	"	
2000			Very weak	"	
2100				"	
2200				Very weak	
2300				" "	
Tensile Strength					
10^3 psi				Av. Yield	Av. Yield
1200°F				349	
1300				337	
1400				319 240	224 211
1500				266 240	
1600				266 239	136 116
1700					131 93
1800					31
Fiber Diameter					
10^{-5} inch				23	50-60
Modulus, 10^6 psi					
Specific Gravity				2.33	

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 15 - SiO_2-Al_2O_3-Nb_2O_5 TERNARY

Glass Number	X-1091 (Cont.)	X-1091	X-1092	X-1093	X-1097
Composition					
SiO_2	89.9		79.9	69.9	59.8
Al_2O_3	5.0		10.0	15.0	0.2
Nb_2O_5	5.0		10.0	15.0	39.9
Fe_2O_3	0.2		0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3650		3340	3240	3520
Fiberizability	OK		OK	OK	Possible
Comments					Devit.
OHB Temp.-°F	3560				
Comments	Viscous				
Fiber Condition					
30 Minutes					
1800°F	Good				
1900	"				
2000	"				
2100	"				
2200	Very weak				
2300	" "				
Tensile Strength					
10^3 psi	Av.	Yield	Av.	Yield	
1400°F	630		266		
1500	524	212			
1600	585	270	242	116	
1700	247	116	185	182	
1800			Yields		
Fiber Diameter					
10^{-5} inch	23-25		39-47		
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 15 - SiO_2-Al_2O_3-Nb_2O_5 TERNARY

Glass Number	X-1098	X-1099	X-1105	X-1106	X-1107
Composition					
SiO_2	54.8	49.9	44.9	39.9	34.9
Al_2O_3	0.2	0.2	0.2	0.2	0.1
Nb_2O_5	44.9	49.9	54.9	59.9	64.9
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3500	3520	3600	3300	3650+
Fiberizability	Possible	Possible	Possible	Negative	Possible
Comments	Devit.	Devit.	Devit.	Too fluid or devit.	Devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 16 - SiO_2-MnO_2-M_xO_y TERNARY

Glass Number	X-961	X-1015	X-1016	X-1017	X-1059
Composition					
SiO_2	96.5	94.5	89.5	89.9	89.5
Al_2O_3	0.4	0.4	0.4	7.0	0.4
MnO_2	3.0	5.0	10.0	3.0	5.0
Fe_2O_3	0.2	0.1	0.1	0.1	0.1
Cr_2O_3					5.0
Iridium Strip Data					
Melting Temp.-°F	3710	3710	3875	3560	3820
Fiberizability	Very good	OK	OK @	OK @	OK
Comments			3800	3740	
OHB Temp.-°F	3605		3550		
Comments					
Fiber Condition					
30 Minutes					
1800°F	Strong		Fair		Strong
1900	Poor		Poor		"
2000			"		Very poor
2100			Very poor		
Tensile Strength					
10^3 psi	Av. Yield		Av. Yield		Av. Yield
1300°F					177
1400			178		
1500	107		166 111		206
1600			195 128		
1700	113		83 (111)		80
1800	54 37				58
1900	80 48				
2000	14				
Fiber Diameter					
10^{-5} inch	145		32		22-24
Modulus, 10^6 psi	11.6		11.9		
Specific Gravity	2.30		2.51		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 16 - SiO_2-MnO_2-M_xO_y TERNARY

Glass Number	X-1060	
Composition		
SiO_2	89.5	
Al_2O_3	0.4	
MnO_2	7.0	
Fe_2O_3	0.1	
Cr_2O_3	3.0	
Iridium Strip Data		
Melting Temp.-°F	3670	
Fiberizability	Possible,	
Comments	but poor	
OHB Temp.-°F		
Comments		
Fiber Condition		
30 Minutes		
Tensile Strength		
10^3 psi		
Fiber Diameter		
10^{-5} inch		
Modulus, 10^6 psi		
Specific Gravity		

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 17 - P_2O_5

Glass Number	X-1048	X-1049	X-1050	X-1051	X-1052
Composition					
P_2O_5	45.0	41.0	36.0	31.0	27.0
CaO	55.0	49.0	44.0	39.0	33.0
Al_2O_3		10.0	20.0	30.0	40.0
Iridium Strip Data					
Melting Temp.-°F	2940	2975	2930	3000	2950
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 17 - P_2O_5

Glass Number	X-1053	X-1054	X-1055	X-1056	X-1057
Composition					
P_2O_5	58.2	50.0	40.0	30.0	15.0
CaO					20.0
Al_2O_3	41.8	50.0	60.0	70.0	65.0
Iridium Strip Data					
Melting Temp.°F	3100	3400	3540	3540	3200
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 18 - SiO_2-WO_3

Glass Number	X-1100	X-1101	X-1108	X-1109	X-1110
Composition					
SiO_2	94.5	89.5	84.6	79.6	74.7
Al_2O_3	0.4	0.4	0.3	0.3	0.3
WO_3	5.0	10.0	14.9	19.9	24.9
Fe_2O_3	0.2	0.2	0.1	0.1	0.1
Iridium Strip Data					
Melting Temp.-°F	3440	3600	3475	3600	3600
Fiberizability	OK @	OK @	Possible	Pulled well	OK @
Comments	3750	3870	@ 3900	@ 3720	3800, but viscous
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
1800°F					Strong
1900					"
2000					Very weak
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 19 - ZrO_2

Glass Number	X-118	X-119	X-1120	X-1121	X-1122
Composition					
ZrO_2	54.6	44.5	34.1	23.2	41.7
Al_2O_3	45.4	55.5	65.9	76.8	
CeO_2					58.3
Iridium Strip Data					
Melting Temp.-°F	3270	3420	3420	3400	4100+
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 19 - ZrO_2

Glass Number	X-1123	X-1124	X-1125	X-1126	X-1127
Composition					
ZrO_2	92.3	90.0	80.0	70.0	60.0
MgO	7.7				
B_2O_3		10.0	20.0	30.0	
ZnO					40.0
Iridium Strip Data					
Melting Temp.-°F	4100	4100	4000	3580	3450
Fiberizability	Negative	Negative	Negative	Negative	Negative
Comments	Not melted	Not melted	Not melted	Incomplete melting	
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 19 - ZrO_2

Glass Number	X-1128	X-1133	X-1155	X-1156	X-1157
Composition					
ZrO_2	62.0	94.0	40.0	38.0	36.0
Al_2O_3			60.0	62.0	64.0
BaO		6.0			
Co_2O_3	38.0				
Iridium Strip Data					
Melting Temp.-°F	3180	4000+	3360	3400	3490
Fiberizability	Negative	Could	Negative	Negative	Negative
Comments	Too fluid or devit.	not melt	Too fluid or devit.	Too fluid or devit.	Too fluid or devit.
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 19 - ZrO_2

Glass Number	X-1158	X-1159	
Composition			
ZrO_2	32.0	30.0	
Al_2O_3	68.0	70.0	
Iridium Strip Data			
Melting Temp.-°F	3500	3495	
Fiberizability	Negative	Negative	
Comments	Too fluid or devit.	Too fluid or devit.	
OHB Temp.-°F			
Comments			
Fiber Condition			
30 Minutes			
Tensile Strength			
10^3 psi			
Fiber Diameter			
10^{-5} inch			
Modulus, 10^6 psi			
Specific Gravity			

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-827	X-830	X-831	X-839	X-842
Composition					
SiO_2		30.0	40.0		30.0
Al_2O_3		0.1	0.1	25.0	17.5
CaO	70.0	49.0	42.0		
ZrO_2	30.0	21.0	18.0		
Fe_2O_3			0.1		
MnO_2				75.0	52.5
Iridium Strip Data					
Melting Temp.-°F	Wouldn't melt	3200	2900	2600	2600
Fiberizability		Could not quench clear	Tendency to fiberize	Too fluid or devit.	Possible Floods
Comments					
OHB Temp.-°F			2435		
Comments			Flooded		
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-843	X-845	X-847	X-860	X-893
Composition					
SiO_2		20.0	30.0	59.8	89.9
Al_2O_3	17.0	13.6	11.9	0.2	5.0
MgO				29.9	
Fe_2O_3			0.1	0.1	0.1
ZnO	83.0	66.4	58.0		
CeO_2					5.0
U_3O_8				10.0	
Iridium Strip Data					
Melting Temp.-°F	2900	2620	2470	2920	3400
Fiberizability	Too fluid or devit.	Possible, but too fluid	Possible, but too fluid	Negative	Fair
Comments					Liquidus high
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-929	X-930	X-951	X-952	X-1002
Composition					
SiO_2	79.6	89.5	94.5	89.6	84.9
Al_2O_3	0.3	0.4	0.4	0.4	5.0
Fe_2O_3	0.1	0.2	0.1	0.1	0.1
ThO_2	10.0	5.0			
TiO_2	10.0	5.0			
Co_2O_3			5.0	10.0	10.0
Iridium Strip Data					
Melting Temp.-°F	3950+	3950+	3600?	3600?	3640
Fiberizability	Possible	OK but	Too	Too	OK @
Comments		melt not clear	viscous @ 3950	viscous @ 3950	3660
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-954	X-955	X-956	X-1001	X-1014
Composition					
SiO_2	98.5	97.5	96.5	94.5	89.9
Al_2O_3	0.4	0.4	0.4	0.4	7.0
Fe_2O_3	0.2	0.2	0.2	0.1	0.1
Cr_2O_3	1.0	2.0	3.0	5.0	3.0
Iridium Strip Data					
Melting Temp.-°F	3900	3950*	3950*	4200	3760
Fiberizability	Too viscous	Too viscous	Too viscous	Not quite melted	Possible
Comments					
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

*Fiberizability not likely.

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-1019	X-958	X-985	X-986	X-1013
Composition					
SiO_2	93.5	94.5	89.5	84.6	84.9
Al_2O_3	0.4	0.4	0.4	0.3	5.0
Fe_2O_3	0.1	0.2	0.1	0.1	0.1
CuO		5.0	10.0	15.0	10.0
Cr_2O_3	3.0				
MnO_2	3.0				
Iridium Strip Data					
Melting Temp.-°F	4100	3960	3900	3900	3800
Fiberizability	Possible	Too viscous	Seedy Possible	Seedy Possible	Seedy Fiberizable
Comments	Melt not clear				after 6 min. @ 3840
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-960	X-987	X-1011	X-1064	X-962
Composition					
SiO_2	94.5	97.0	98.5	99.5	94.5
Al_2O_3	0.4	0.4	0.4		0.4
Fe_2O_3	0.1	0.1	0.2		0.1
Li_2O	5.0	2.5	1.0	0.5	
Na_2O					5.0
Iridium Strip Data					
Melting Temp.-°F	2860	2960	3160	3080	2950
	Seedy	Seedy		Seedy	
Fiberizability	OK	Possible	OK	OK @	OK
Comments		over 2960		3600	Viscous
OHB Temp.-°F					
Comments					
Fiber Condition					
30 Minutes					
Tensile Strength					
10^3 psi					
Fiber Diameter					
10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-966	X-967	X-1112	X-1113	X-1114
Composition					
SiO_2	94.5	89.5	84.9	79.9	84.6
Al_2O_3	0.4	0.4	10.0	10.0	0.3
Fe_2O_3	0.1	0.1	0.1	0.1	0.1
SnO_2	5.0	10.0	5.0	10.0	10.0
ZrO_2					5.0
Iridium Strip Data					
Melting Temp.-°F	3500 Seedy	3800+	3520	3640	4000+
Fiberizability	Too viscous	Too viscous @ 4000	Fair @ 3570	OK	Possible
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-1115	X-1116	X-1176	X-1177	X-1179
Composition					
SiO_2	84.6	79.6	74.7	69.7	84.6
Al_2O_3	0.3	0.3	0.3	0.3	0.3
Fe_2O_3	0.1	0.1	0.1	0.1	0.2
SnO_2	5.0	10.0	12.5	14.9	14.9
ZrO_2	10.0	10.0	12.5	14.9	
Iridium Strip Data					
Melting Temp.-°F	3690	4000	4000	4030	4050
Fiberizability	Possible but viscous	Negative Too viscous	OK	OK	OK, but required stirring
Comments					
OHB Temp.-°F					
Comments					
Fiber Condition 30 Minutes					
Tensile Strength 10^3 psi					
Fiber Diameter 10^{-5} inch					
Modulus, 10^6 psi					
Specific Gravity					

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 20 - MISCELLANEOUS

Glass Number	X-1180	X-1178	X-1183	
Composition				
SiO_2	79.6	96.5	94.5	
Al_2O_3	0.3	0.4	0.4	
Fe_2O_3	0.2	0.2	0.2	
Ag_2O		3.0	5.0	
SnO_2	19.9			
Iridium Strip Data				
Melting Temp.-°F	4050	4000	4000	
Fiberizability	OK, but required stirring	OK	OK	
Comments			viscous	
OHB Temp.-°F				
Comments				
Fiber Condition 30 Minutes				
Tensile Strength 10^3 psi				
Fiber Diameter 10^{-5} inch				
Modulus, 10^6 psi				
Specific Gravity				

TABLE II - GLASS COMPOSITION AND PROPERTY DATA
GROUP 21 - MISCELLANEOUS RUN IN OHB

Glass Number	X-953	X-959	X-971	X-972	X-1111
Composition					
SiO_2	84.6	94.5	94.6	89.7	84.9
Al_2O_3	0.3	0.4	0.4	0.4	5.0
Fe_2O_3	0.1	0.1	5.0	10.0	0.1
Co_2O_3	14.9				
K_2O		5.0			
SnO_2					10.0
Iridium Strip Data					
Melting Temp.-°F	3600	2940	3720	3800	3700
Fiberizability	OK @ 3750	OK @ 3150	OK @ 3920		OK @ 3750
Comments					
OHB Temp.-°F	3530	3030	3600		
Comments			Temp. too low		
Fiber Condition					
30 Minutes					
1800°F	Strong	Weak	*Strong	Strong	Strong
1900	Brittle		Brittle	"	"
2000	Very weak		"	Very weak	"
2100			"	" "	"
2200			Very weak		
Tensile Strength					
10^3 psi	Av. Yield	Av. Yield		Av. Yield	Av. Yield
1100°F		195 164			
1300		150 103			131
1400					109 65
1500	95	40		83 48	69 45
1600				107 82	Yields
1700				97 75	
1800				65 37	
1900				Yields	
Fiber Diameter					
10^{-5} inch	68	46		60-90 Variable	56-64
Modulus, 10^6 psi	11.6	10.0 approx.		12.7 approx.	
Specific Gravity	2.40	2.26			

*Very coarse fibers

TABLE II

GLASS COMPOSITION AND PROPERTY DATA
GROUP 21 - MISCELLANEOUS RUN IN OHB

Glass Number	X-1117	X-1151	
Composition			
SiO_2	46.9	48.0	
Al_2O_3	45.0	32.2	
Fe_2O_3	1.0	0.9	
Na_2O	0.6	1.3	
K_2O	0.6	0.6	
ZrO_2	4.6	5.0	
ZnO	0.7		
MgO		11.4	
TiO_2	0.4		
F_2	0.3	0.4	
Iridium Strip Data			
Melting Temp.-°F	Too fluid		
Fiberizability	to run @ 3320		
Comments	Devit. above		
OHB Temp.-°F			
Comments			
Fiber Condition			
30 Minutes			
Tensile Strength			
10^3 psi		Av.	Yield
900		277	260
1100		234	225
1200		140	113
1300		Yields	
Fiber Diameter			
10^{-5} inch		33-44	
Modulus, 10^6 psi		13	
Specific Gravity		2.70	

PHASE II

IMPROVEMENT IN HIGH MODULUS GLASS LAMINATES

INTRODUCTION

Test data on YM31A glass fabric laminates obtained from previous work (Contract AF 33(616)-5802 Supplement 1) were limited in relation to the quantities of background information available on conventional "E" glass reinforcements. These data indicated, however, that while the moduli of the laminates were usually substantially increased, the strengths were generally lower than similar "E" glass moldings. It is the object of this portion of work, therefore, to obtain laminates reinforced with YM31A glass having strength properties at least equivalent to those of "E" glass, particularly wet strength.

Since all YM31A glass can only be formed on a 51 filament bushing, extra processing is necessary in constructing a 204 filament strand. Damage incurred through extra processing may be a possible cause for the lower laminate strengths. 204 filament yarns were constructed from 51 filament strands and woven into 181 style fabric. This fabric was compared to commercially available 181 style fabric for use as a reinforcement for plastic laminates.

YM31A glass may also be more sensitive to heat than is "E" glass and, therefore, both chemical methods and heat were used to remove 630 size from the glass. Previous work indicated much greater differences occurred among the various finishes used with YM31A than with similar moldings of "E" glass. A larger portion of work was, therefore, concerned with the study of both methods of size removal as well as processes variations in finish application.

SUMMARY

The development of the high modulus glass fiber composition YM31A offers new potential uses for glass reinforced plastics. To fully realize this potential, several process variations were studied to obtain information on the behavior of YM31A glass as a reinforcement for plastics. Fabric construction variations, methods of 630 size removal to minimize damage to the glass, methods of applying finish to glass yarns, resin matrices, and reinforcement structures were evaluated.

In order to study the effect of fabric construction on the properties of plastic laminates, "E" glass 181 style fabric was woven from yarns constructed of 51 filament strands and compared in molded laminates with

conventional 181 fabric woven from yarns constructed of 204 filament strands. The results obtained with polyester resin as the matrix material indicated no significant difference in laminate strengths between the two fabrics of different yarn constructions.

Combinations of solvents, enzymes and chemicals were coupled with short-time heat treatments in an effort to remove the original 630 size and leave the glass relatively undamaged. No system was found which could remove all of the size without a subsequent short-time heat treatment. No chemical method of size removal was found to be better than the standard heat cleaning procedure when evaluated with molded specimens.

The type of reinforcement and the resin-finish system both have an effect on the strength of YM31A glass moldings. With Epon 828 and A-1100 finish, moldings reinforced with YM31A 128, 143 style fabrics and parallel strand reinforcement showed higher strengths than similar "E" glass moldings. With Paraplex P-43 and Volan A treatment, YM31A parallel strand and 143 style fabric reinforcement were stronger than similar "E" glass moldings; but YM31A 128 and 181 style fabric reinforcement gave lower strengths than similar "E" glass moldings.

Yarn constrainment, caused by weave interlacings, reduces the effectiveness of YM31A glass as a reinforcement. The degree of constraint is a function of the number of yarn interlacings and bulkiness of the fill yarns, i.e., plain woven material (128 style fabric) imposes more constraint on woven yarns than an 8-harness satin weave (181 style fabric). Removal of this constraint by use of a crow foot satin weave (143 style fabric-unidirectional weave) or parallel strand reinforcement resulted in strengths of YM31A glass laminates which were higher than "E" glass reinforced moldings using Paraplex P-43 resin.

Epon 828 epoxy resin is a better matrix material for YM31A glass than Paraplex P-43 resin regardless of the structure of the reinforcement. Epon 828 is not only a stronger adhesive than Paraplex P-43, but is also a more ductile material. A combination of better adhesion and lower resin modulus allows better distribution of stresses during testing, because the yarns, imbedded in the material can deform to absorb the applied loads.

A study of resin-finish combinations revealed that Epon 828 epoxy resin and A-1100 finish was the best system of all those investigated for YM31A glass. Use of this resin-finish combination and parallel strand YM31A glass reinforcement effected an 11 percent increase in wet flexural strength over "E" glass reinforced bars. This resin-finish combination and YM31A glass also effected a 34 percent increase in wet flexural modulus over bars reinforced with "E" glass. Other epoxy resins reinforced with YM31A glass should also exhibit better flexural properties than similar moldings of "E" glass, provided that A-1100 finish is used.

Bars made from CTL 91-LD phenolic resin and A-1100 finished YM31A glass were stronger than similar "E" glass moldings. Additional

information should be obtained to confirm these findings. These results are, therefore, presented only as indications.

Moldings made with DC-2106 silicone resin and YM31A glass using T-31 finish exhibited poorer properties than similar moldings of "E" glass. In general, properties of bars reinforced with either glass were lower than any resin-finish system studied.

Since so few moldings were made with Vibrin 136A heat resistant polyester resins and the results obtained were inconsistent, no conclusions should be drawn.

Additional information on molding conditions is presented in the Conclusions and Recommendations as well as in the text.

DISCUSSION

Fabric Construction Variations

All of the YM31A glass used in previous work was woven into 181 style fabric with yarn having a different construction than conventional "E" glass yarn. The difference in yarn construction between the two glass compositions used is shown in the following table:

TABLE III

YARN CONSTRUCTIONS - YM31A VS "E" GLASS

Glass Type	Number of Filaments Per Strand	Strand Yardage Per Pound	Twist and Ply	Final Twist tpi
YM31A	51	527×10^2	4/2	3.8
"E"	204	150×10^2	1/2	3.8
"E"	204	225×10^2	1/3	3.8

To determine if any difference existed between a 51 and a 204 filament strand on the strengths of reinforced plastic laminates, fabric was woven from what was considered to be equivalently constructed yarns. The fabric, woven from an "E" glass yarn composed of 51 strand (G 600 4/2's), was sent to Glass Fabrics Finishing Company, Cedar Grove, New Jersey, for batch heat cleaning and finishing. In all, 50 yards of 181

fabric were woven. Half of the fabric was treated with Garan finish and the other half with Volan A finish. These fabrics were then compared with commercially available 181 "E" glass fabric (204 filament strand) both for fabric properties and properties of laminates reinforced with them.

Fabric Properties

The results obtained for fabric properties are presented in Table IV.

TABLE IV

FABRIC PROPERTIES FOR 51 AND 204 FILAMENT "E" GLASS FINISHED WITH VOLAN A AND GARAN

Fabric and Finish	Yarn Count		Fabric Thickness mils	Ignition Loss %	Ounces per Yard
	Warp	Filling			
181 - Volan A 51 Filament	57	54	11.7	0.126	8.11
181 - Volan A 204 Filament	55	54	13.0	0.130	8.54
181 - Garan 51 Filament	58	54	13.7	0.098	8.00
181 - Garan 204 Filament	58	54	13.8	0.100	8.57
All data presented are averages of five determinations.					

Discussion of Results. The results presented in Table IV indicate that not all properties tested are consistent among fabrics, but differences shown may or may not have made a significant influence on panel properties.

Laminates Made From 51 and 204 Filament "E" Glass Fabrics

12-ply laminates were molded under the following conditions:

Resin: 90 parts Paraplex P-43
10 parts Styrene
1 part Benzoyl Peroxide

Fabric Finish:	Volan or Garan (Plies for each laminate were selected randomly from available stock.)
Cure Temperature:	230°F
Cure Time:	15 minutes
Molding Pressure:	20 psi

The results obtained for all properties are presented in Table V.

Discussion of Results. Laminates of Garan finished fabrics indicate no significant differences between the two yarn constructions. Based upon these results, it is believed that no real strength advantage would be obtained with 204-filament strands formed directly from 204-hole bushings. Conversely, no significant damage was caused by constructing 204-filament strands from four 51-filament strands.

Comparison of the laminates made of Volan A finished fabrics constructed of 204-filament versus 51-filament strands was rendered inconclusive due to atypically high flexural strengths for the 204-filament strand set. Based on other data for standard Volan A finished 181 "E" glass fabric, it is concluded the abnormality is due to finish rather than to the yarn construction variable under scrutiny.

Surface Treatments for YM31A Glass

Previous work has shown that YM31A glass fibers, yarns, and fabrics are as strong as "E" glass materials. The strengths of laminates made from YM31A glass generally, however, were lower than laminates made from "E" glass. Based on these results, it was concluded that a study should be made to determine the effect of variations in heat cleaning and finishing on strengths of YM31A glass and subsequent molded laminates. It is the objective of this work, therefore, to (1) find a desizing and finishing technique that minimizes damage to YM31A glass, and (2) to obtain better glass-finish bonds which would result in strengths of laminates made from YM31A glass equal to or better than molded parts made from "E" glass.

Strands of glass fibers are held together and protected against abrasion during their processing into yarns and fabrics by the application of a protective coating at the forming bushing. A standard protective coating (630 size) is mainly composed of a modified starch and oily lubricants. The starchy portion of the size acts as a film former, that is, it coats fiber surfaces with a thin film. Application of only a starch film would result in a relatively stiff strand. In order to reduce the stiffness of the starch film, lubricants are added to the size. Addition of lubricants not only increases flexibility of the starch film, but also aids in wetting of the glass surface, and imparts lubrication to the filaments.

TABLE V

PROPERTIES OF 12 PLY LAMINATES MADE WITH 51 AND 204 FILAMENT "E" GLASS

RESIN: Paraplex P-43
FINISH: Volan A and Garan

Fabric and Finish Used	Flexural Strength x 10^3 psi*		Flexural Modulus x 10^6 psi*		Compressive Strength x 10^3 psi		Compressive Modulus x 10^6 psi		Glass by Volume %**	Specific Gravity**
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		
181 - Volan A 51 Filament	69.8	45.5	3.70	3.23	37.5	23.3	4.44	4.02	52.8	1.89
181 - Volan A 204 Filament	79.9	57.2	3.77	3.41	42.3	32.4	4.31	4.05	53.5	1.92
181 - Garan 51 Filament	67.4	62.1	3.59	3.44	44.2	40.3	4.21	3.87	48.3	1.82
181 - Garan 204 Filament	67.1	63.1	3.45	3.36	37.8	39.8	4.09	4.33	47.7	1.81

*All strength and modulus measurements presented are averages of 5 tests on 3 laminates.
**Data presented are averages of 2 tests on 3 laminates.
Unless otherwise specified, all samples were tested wet after a 2 hour boil in distilled water.

It is known that plastic laminates made from 630 sized material have poorer properties than those made from cleaned and finished glass. The presence of standard 630 size on glass inhibits formation of a good resin-glass bond. In order to obtain best laminate properties, a resin-compatible size must be used originally, or the size must be removed chemically or with heat before the application of a resin-compatible finish.

The work done has been divided into two sections: the effect of size removal methods and the effect of temperature on YM31A glass tape. Several methods used to desize or clean greige glass materials were evaluated by measuring ignition losses. Tensile strengths of some heat treated tapes have also been obtained to determine the effect of temperature and desizing methods on tape strength. Six-inch samples of YM31A glass tape were used throughout all of the work. This tape was 3/4-inch wide, 32 ends and 32 pics in a plain weave approximately that of 128 style fabric.

Evaluation of Methods for Size Removal

Standard 630 size, on glass fiber surfaces, comprises oily lubricants and a modified starch. The lubricant portion of the size can be removed by extraction with suitable solvents. Solvent extraction alone, however, does not remove the starchy component of the size. Therefore, some other means must be used to remove the starch. Six methods were used to remove 630 size from glass tape. These were:

1. Solvent extraction plus enzyme digestion
2. Ammonium hydroxide boil plus enzyme digestion
3. Detergent scour plus enzyme digestion
4. Enzyme digestion
5. Chemical oxidation
6. Strong alkali soak

Solvent Extraction Plus Enzyme Digestion. In the evaluation of solvent extraction and enzyme digestion the procedure consisted of immersing greige tape in boiling solvent for ten minutes, followed by rinsing twice in clean boiling solvent. Those tapes extracted with high boiling point solvents were rinsed in clean acetone prior to drying at room temperature. The starchy portion of the size, remaining on the glass after solvent extraction, was digested using an enzyme solution containing one per cent Rhozyme DX and 0.07 per cent Triton X-100. All of the starch was removed in 1/2 hour at 180°F using this solution. This was verified by an iodine test. The tape was then rinsed in distilled water and dried.

The solvents used and ignition losses obtained for all solvent extracted-enzyme desized tape are presented in Table VI. These results indicate that most of the size has been removed from the solvent cleaned

glass. However, a residue was present even after enzyme digestion; heating for three minutes at 700°F removed most of the size residue on the glass. This was a convenient temperature to determine how easily the residual size could be removed. The ignition losses obtained are also presented in Table VI.

To determine the reproducibility of the results, two additional samples were prepared using the Stoddard solvent-enzyme digestion system. Ignition losses obtained on the two re-runs were 0.10 per cent and 0.08 per cent, respectively. This indicates that the differences between the solvents are significant and not due to experimental error.

TABLE VI

IGNITION LOSSES - YM31A GLASS TAPES

SOLVENT EXTRACTION - ENZYME DESIZE

Solvent	Ignition Loss (%)*	Ignition Loss (%) After Additional Treatment for 3 minutes at 700°F
Acetone	0.11	below 0.10
Carbon Tetrachloride	0.23	below 0.10
Cyclohexanol	0.21	below 0.10
Ethanol	0.23	below 0.10
Perchloroethylene**	0.23	below 0.10
Stoddard Solvent**	0.10	below 0.10
Toluene	0.16	below 0.10

*Single determinations
**Residual solvent removed by rinsing in clean acetone.

Ammonium Hydroxide Boil Plus Enzyme Digestion, Detergent Scour Plus Enzyme Digestion, and Enzyme Digestion Alone. Separate samples of greige tape were boiled in the following solutions:

a. 1% ammonium hydroxide for 30 minutes.
b. 1% solution of Triton X-100 for 20 minutes.

All samples were then treated in a solution which contained one per cent Rhozyme DX and 0.07 per cent Triton X-100 for 1/2 hour at 180°F.

Ignition losses obtained for treated samples are shown in Table VII. These treatments used were not as effective as the solvent extraction-enzyme digestion cleaning systems. Additional treatment of the samples for three minutes at 700°F removed more of the residual size; however, even after this treatment some size remained on the boiled samples.

TABLE VII

IGNITION LOSSES OBTAINED FOR CHEMICAL SIZE REMOVAL SYSTEMS FOR YM31A GLASS TAPE

Type Treatment Used	Enzyme Desize	Ignition Loss (%)*	Ignition Loss (%) After Additional Treatment For 3 Minutes at 700°F
Ammonium Hydroxide 1% solution**	Yes	0.30	0.10
Triton X-100 1% solution***	Yes	0.27	0.10
Enzyme Alone	Yes	0.44	below 0.10

*Ignition losses based on single determinations
**Boiled 30 minutes
***Boiled 20 minutes

Chemical Oxidation. The procedure used consisted of immersing a greige tape in a solution containing 5 per cent sodium chlorate and 0.01 per cent Triton X-100 for one hour at 170°F. The tape was then rinsed in distilled water, dried, then exposed for three minutes to temperatures near 700°F.

Ignition losses obtained for both heated and unheated samples are presented in Table VIII. These results indicate that some residue remains on the glass treated with sodium chlorate. Before heat treating the sodium chlorate desized samples contained more residue than did the solvent extracted samples. However, exposure to 700°F for three minutes reduced residual size to less than 0.10 per cent in both cases.

TABLE VIII

IGNITION LOSS OBTAINED ON ALKALINE DESIZED, OXIDATIVE DESIZED, AND HEAT TREATED YM31A GLASS TAPE

Type Treatment	Ignition Loss (%)*	Heat Treated Ignition Loss (%)
Oxidative Desize	0.30	below 0.10 - 3 minutes at 700°F
(Sodium Chlorate)	0.24	below 0.10 - 3 minutes at 700°F
Alkaline Desize	0.57	0.10 - 4 minutes at 600°F
(Sodium Hydroxide)	0.64	0.12 - 8 minutes at 600°F
	0.54	below 0.10 - 6 minutes at 800°F
	0.77	below 0.10 - 8 minutes at 800°F
Heat Treatment	2.08**	

*Single determinations.
**Ignition loss (average 7 determinations) for greige tape.

Strong Alkali Soak. The procedure comprised four steps:

a. Soaking greige materials for one hour at room temperature in one per cent sodium hydroxide (pH 11-13).
b. Rinsing the material until the rinse water had a pH close to 7.
c. Air drying the material.
d. Heating at 600 - 800°F for 4-8 minutes.

The ignition losses presented in Table VIII indicate that the strong alkali treatment removed most of the size. However, the treatment was not as effective as previously discussed desize systems - residues were higher than for any of them. These results also indicate that most of the remaining size had been burned off by exposure to 800°F. Heating at 600°F did not remove all of the residue.

Heat Treating Alone. Greige glass tape was treated for three minutes at 700°F to determine per cent of size removed at this temperature. Ignition losses obtained are presented in Table VIII. The results show that most of the size has been burned from the glass tape at 700°F; the tape had an ignition loss as low as the tape which was first chemically desized. The question may arise, "Why then, must a chemical desize system be used in conjunction with heat cleaning?" Six-inch samples of greige tape, when exposed to heat in open form, can have most of the textile size removed, because all of the size is on the surface of the exposed glass. However, in commercial heat cleaning, rolls of glass fabric do not have all of their surface exposed. The fabric is batch heat cleaned which requires a long time at the high temperature

to effectively remove most of the 630 textile size.

Theoretical Considerations. None of the chemical systems used in desizing fibrous glass materials removed all of the textile size. An attempt was made, based on theoretical considerations, to determine which of the size components still remained on the glass after solvent cleaning. Standard 630 size comprises the following materials:

630 Size Components (Dry Basis)	Weight %	Lubricant* Wt. (%)
Dextrin	77.4	----
Vegetable Oil	17.9	79.3
Vegetable Oil Emulsifier	1.7	7.5
Cationic Softener	1.7	7.5
Gelatin	0.5	2.2
Polyvinylacetate	0.8	3.5
	100.0	100.0

*All except dextrin is considered lubricant

The actual amount of dextrin removed by enzyme treatment alone is in good correlation with the theoretical amount present on the fiber. Enzyme treatment should remove the starchy portion of the size. Actually, 0.44 per cent residue (Table VII) remained on the enzyme desized sample. This ignition loss, 0.44 per cent, expressed as a percentage of the total average ignition loss (2.08 per cent, Table VIII) is 21.1 per cent. This means that 78.9 per cent was removed by the enzyme treatment. Comparison of these values with the theoretical calculated values shows the following:

Enzyme Desized

Actual Values	Theoretical Values
78.9% dextrin removed	77.4% dextrin present
21.1% residue	22.6% lubricants present

These results indicate that the enzyme treated tapes contained a residue which is composed mainly of lubricants.

Further analysis of results obtained for solvent extracted and enzyme desized samples indicates that some lubricant is still present on the glass after solvent extraction. An average of ignition losses obtained from solvent extracted samples (0.18, taken from Table VI) expressed as a percentage of the total average ignition loss (2.08%) yields a value of 8.6 per cent. Theoretically, size components that should be easily extracted, solubilized or digested are dextrin, vegetable oil, emulsifier and polyvinylacetate. The cationic softener and gelatin may bond or adhere to the glass surface. Addition of the amounts of cationic softener and gelatin, expressed as a percentage of total lubricant present, yields a value of 9.7 per cent. A comparison of

the two values shows the following:

Solvent Extracted - Enzyme Desized

Actual Value	Theoretical Value
8.6% residue	9.7% cationic softener and gelatin present

It is possible, therefore, that the residue present on the glass after solvent extraction and enzyme digestion is composed of the cationic softener and gelatin. Short heat cleaning cycles can be used to remove this residue present after solvent extraction and enzyme digestion.

Chemical methods of cleaning glass other than enzyme desizing and/or solvent extraction left more residue on the glass surface prior to heat treating. This can be explained on the basis of incomplete dextrin removal.

Evaluation of Heat Cleaning and Desizing Variations in Relation to Strength

The Effect of Heat on YM31A and "E" Glass Tapes. A study was made to determine the effect of heat on YM31A and "E" glass tapes. Prior to heat treatment, all tapes were desized and solvent extracted with an aqueous solution containing one per cent Rhozyme DX and 0.07 per cent Triton X-100 followed by a boil in acetone. By removing most of the starch film and oily lubricants from the glass surface, it was believed that a better measurement of heat effects could be obtained. All samples were heated in a muffle oven for one hour at each treatment temperature. YM31A glass tape contained 32 ends whereas "E" glass tape contained 30 ends. The results obtained are presented in Table IX.

Discussion of Results. The results obtained indicate that YM31A glass is more sensitive to heat than "E" glass.

Six-inch strips of greige, solvent extracted, and enzyme desized tapes were treated at 400°F and 550°F in a Grieve-Hendry forced air oven for various lengths of time. It is believed that the muffle oven may give good relative results, but because of the limited space and radiant heat from the walls, it may be more severe on the glass being treated than the Grieve-Hendry oven. The tensile strengths obtained at the two temperature levels are shown in Table X; each point shown is an average of five tensile breaks.

The results shown in Table X indicate that unheated solvent extracted and enzyme desized samples had lower strengths than did unheated

TABLE IX

EFFECT OF HEAT TREATMENTS ON YM31A AND "E" GLASS TAPES

Heat Treatment Temperature	Breaking Load Tension (Lbs.)	
	YM31A Glass	"E" Glass
No treatment	167	122
1 hr. at 350°F	169	132
1 hr. at 450°F	151	106
1 hr. at 600°F	100	55
1 hr. at 800°F	92	47
1 hr. at 1000°F	14	44
Data presented are averages of five tests per sample of tape.		

greige tape. An acetone extraction effectively removes most of the lubricant portion of size leaving a glass surface with less resistance to abrasion. An enzyme desize removes only the starchy film which envelops and protects the glass filaments. Loss of either the lubricant or the starch film lowers resistance of the glass to abrasion, which in turn, can result in lower strengths.

Heating YM31A glass tape at 550°F reduced tape strengths for all samples. The standard deviation of individual tensile strength calculated from all the data was $\pm$ 15.2 which indicates considerable variation in tape strength. Nevertheless the effect of heat on YM31A glass for greige, acetone extracted, and enzyme desized tape shows a trend toward lower strength for longer treatments at 550°F. This loss in YM31A tape strength at 550°F may occur for two possible reasons (1) loss of lubrication or protective film and (2) thermal damage. The strength of tapes treated for 23 hours at 400 and 550°F after both solvent extraction and enzyme desizing shows strength losses of 39.5 and 45.0 per cent respectively.

In order to assess the degree of temperature sensitivity a comparison was made of YM31A and "E" glass tapes, evaluated by measuring the strengths of molded specimens. This study is presented in the following section.

TABLE X

THE EFFECT OF HEAT TREATMENTS ON THE STRENGTH OF GREIGE, SOLVENT EXTRACTED, AND ENZYME DESIZED YM31A GLASS TAPE

Surface Treatment	Heat Treatment Temperature	Hours at Each Temperature					
		0	1	3	5	7	23
Greige YM31A Tape	400°F	217	257	242	240	250	229
	550°F	236	178	177	176	171	167
Acetone Extracted YM31A Tape	400°F	196	196	210	193	191	182
	550°F	213	-	168	157	141	110
Enzyme Desized YM31A Tape	400°F	164	205	219	201	201	204
	550°F	168	-	151	140	146	111

Each value is the average of five tensile breaks expressed in pounds.

Standard deviation of individual breaks calculated from all the data was ± 15.2.

Heat Cleaning Variations. A study was made with 630 sized YM31A tape to determine the effect of variations in the heat cleaning cycle on the strength of bar moldings. The tape was heated for various times and temperatures. Bar moldings were made using Volan A finished YM31A tape (30 ends) and Paraplex P-43 resin. Results are presented in Table XI.

TABLE XI

EFFECT OF HEAT CLEANING CYCLE ON PROPERTIES OF BAR MOLDINGS MADE FROM YM31A GLASS TAPE

Heat Cleaning Cycle 15 hrs at 500°F Followed by	Ignition Loss of Tape (%)	Wet Flexural Strength, 10^3 psi	Wet Flexural Modulus, 10^6 psi	% Glass by Volume
55 hrs at 550	0.15	48.6	3.49	
75 hrs at 550	0.17	46.8	3.48	42.6
65 hrs at 600	0.05	49.0	3.60	43.0
55 hrs at 650	0.04	46.0	3.47	42.3
75 hrs at 650	0.01	48.8	3.42	42.6

Discussion of Results. The ignition losses obtained indicate that a temperature of 550°F does not remove all of the size from the glass even when extended beyond the normal time of 65 hours. Even though some size still remained on the glass after heat cleaning at 550°F, the amount present is still within specification (below 0.20 per cent).

Laminate strengths obtained show no significant variation within the temperature range studied. At the 95 per cent confidence level, each value has a range of about ± 2,000 psi. It is concluded that small variations in the heat cleaning cycle will not improve the strength of YM31A polyester

laminates. The strengths of heat cleaned glass tape probably cannot be related to the flexural strengths of reinforced plastics. The work done did help to indicate the direction and magnitude of damage by various thermal treatments and their general effects on laminate strengths.

Chemical Methods of Size Removal - Moldings with Polyester Resin. Four methods of size removal were evaluated in a balanced 16-run experiment which included two variations in applying A-172 finish. The complete experiment included the following variables:

Experimental Design $4 \times 2^{3-1}$ (e.g., One variable at 4 levels, three variables at 2 levels. The experiment contained $4 \times 2^{3-1}$ or 16 moldings).

	Variable Levels		
Variables	Level 1	Level 2	
Glass Type	"E" Glass	YM31A Glass	
Type of Size Removal	[1]Heat Cleaning (standard cycle) [2]Solvent Extraction plus Enzyme Desize [3]Caustic Treatment [4]Oxidative Desize		All followed by 15 hours at 650°F
Finish Bath pH-A-172	Acidic	Basic	
Finish Cure Temperature	Room Temperature (1-week min)	10 minutes at 300°F	

[1]Heat Cleaning. The material was treated for 15 hours at 500°F and 65 hours at 650°F.

[2]Solvent Extraction plus Enzyme Desize. The material was boiled in acetone, rinsed twice in clean boiling acetone, treated for 1/2 hour at 180°F in one per cent Rhozyme DX and 0.07 per cent Triton X-100 solution, rinsed, and dried.

[3]Caustic Treatment. The material was soaked in a one per cent solution of sodium hydroxide at room temperature, then washed with water until the rinse water tested to a pH of 7.

[4]Oxidative Desize. The material was treated at 170°F for one hour in a five per cent aqueous solution of sodium chlorate which contained 0.1 per cent Triton X-100 by volume.

TABLE XII

MOLDING CONDITIONS FOR BAR MOLDINGS REINFORCED "E" AND YM31A GLASS TAPE

RESIN: Paraplex P-43
FINISH: A-172

Specimen Number	Class	Size Removal Method	pH of Finish Bath	Temperature of Finish Cure
1	"E"	Heat Cleaned	acid	Room Temperature
2	YM31A	Heat Cleaned	acid	10 min. at 300°F
3	"E"	Enzyme Desize	acid	10 min. at 300°F
4	YM31A	Enzyme Desize	acid	Room Temperature
5	"E"	Caustic Desize	acid	10 min. at 300°F
6	YM31A	Caustic Desize	acid	Room Temperature
7	"E"	Oxidative Desize	acid	Room Temperature
8	YM31A	Oxidative Desize	acid	10 min. at 300°F
9	"E"	Heat Cleaned	basic	10 min. at 300°F
10	YM31A	Heat Cleaned	basic	Room Temperature
11	"E"	Enzyme Desize	basic	Room Temperature
12	YM31A	Enzyme Desize	basic	10 min. at 300°F
13	"E"	Caustic Desize	basic	Room Temperature
14	YM31A	Caustic Desize	basic	10 min. at 300°F
15	"E"	Oxidative Desize	basic	10 min. at 300°F
16	YM31A	Oxidative Desize	basic	Room Temperature

The method used for preparing each specimen is presented in Table XII.

Bar moldings were prepared using 17 plies of woven tape as the reinforcement.

Resin and cure conditions were:

Resin:	90 parts Paraplex P-43 10 parts styrene 1 part benzoyl peroxide
Cure Temperature:	230°F
Cure Time:	15 minutes

A summary of experimental results calculated from test data is presented in Table XIII. The finish cure temperature was not found to be a significant variable and is not included in the table.

TABLE XIII

EXPERIMENT FOR INVESTIGATING FOUR METHODS OF SIZE REMOVAL AND TWO METHODS OF APPLYING A-172 FINISH
RESIN: PARAPLEX P-43

	Wet Flexural Strength x 10^3 psi*			
	"D" Glass		Y-31A Glass	
	Acid A-172	Basic A-172	Acid A-172	Basic A-172
Heat Cleaning	45.4	43.9	39.9	38.5
Solvent Extraction & Enzyme Desize	43.9	45.4	42.3	43.8
Caustic Treatment	45.9	47.3	40.4	41.8
Oxidative Desize	43.5	42.0	41.8	40.4

The standard deviation of presented values is 0.56 x 10^3 psi
*after 2-hour boil.

Discussion of Results. Based on wet flexural strength data presented in Table XIII, the following conclusions can be drawn:

1. The properties of bars reinforced with YM31A glass tape never equalled or exceeded the best value using "E" glass tape.
2. The desizing technique giving highest flexural strength with YM31A glass involved solvent extraction - enzyme digestion treatment in conjunction with alkaline finishing bath conditions. (This complete system is not recommended. See discussions on modulus below.)
3. Heat cleaning was the poorest method for desizing YM31A glass. All three chemical systems gave higher strengths.
4. The best strengths with "E" glass were obtained using a caustic desize, but this would probably be uneconomical for the small improvement.

None of the desizing methods affected the wet flexural modulus. For this property, the only critical variables were the pH of the finish bath and the glass type, as shown in Table XIV.

TABLE XIV

EFFECT OF pH OF A-172 FINISH
ON WET FLEXURAL MODULUS OF BAR HOLDINGS

	Flexural Modulus, 10^6 psi	
	"E" Glass	YM31A Glass
Acid A-172	2.86	3.34
Alkaline A-172	2.84	2.72
Standard deviation of presented values is 0.03 x 10^6 psi.		

Finished under the acid condition, YM31A glass had a 17 per cent increase in modulus over "E" glass. Under alkaline conditions, it was actually lower than "E" glass. Our hypothesis is that hydrolysis of the finish on the YM31A glass surface was impaired in a basic finish solution. It is believed that this allowed slippage of the resin-finish bond, resulting in a lower modulus. The slippage also may account for

the slightly higher flexural strength - via the route of better stress distribution as the test load is applied.

Test data for flexural strength, flexural modulus, glass by volume, ignition loss, and specific gravity are presented in Appendix, Table LIII.

Chemical Methods of Size Removal - Moldings with Epoxy Resin. The previous experiment evaluated several different methods of 630 size removal from glass tape using specimens molded with Paraplex P-43 polyester resin. The data obtained indicated that batch heat cleaned reinforcement resulted in slightly lower specimen wet flexural strengths than did use of chemically cleaned materials. Acetone extraction - enzyme digestion followed by 15 hours at 650°F increased the wet flexural strength of bar moldings, and was chosen for further evaluation with an epoxy resin. The best resin-finish system for YM31A glass to date, has been Epon 828 epoxy resin and A-1100 finish. To further investigate this system and confirm the results obtained with Epon 828, the following experiment was performed to evaluate two methods of size removal. The methods studied were:

1. Acetone extraction-enzyme digestion followed by additional heat treatment for 15 hours at 650°F. The chemical method alone removes most of the 630 size from the glass material. Specifically, 0.11 per cent residual size remains on the chemically treated tape. To remove this residue the chemical desizing system was followed by heating at 650°F for 15 hours.

2. Standard batch heat cleaning. This method consists of treating the glass for 15 hours at 500°F, then for 65 hours at 650°F.

Both methods of size removal were evaluated in bar moldings using 17 plies of "E" or YM31A glass tape as the reinforcement. Molding conditions used were:

Finish:	A-1100
Resin:	Epon 828/CL (14 pph of CL, meta-phenylene diamine)
Primary Cure:	one hour at 250°F
Post Cure:	one hour at 375°F

In all, 16 bar moldings were made and tested for both dry and wet compressive and flexural properties. The results obtained are presented in Table XV.

Discussion of Results. Heat cleaned "E" and YM31A glass reinforced bars show significant increases in dry flexural strength over bars made from chemically desized glass. The results obtained with both glasses for all other properties show no significant difference between methods of size removal. The increase in dry flexural strengths noted can probably be explained on the basis of better adhesion between the resin and glass.

TABLE XV

EXPERIMENT FOR DETERMINING THE EFFECT OF DIFFERENT METHODS OF 630 SIZE REMOVAL ON BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS TAPE

RESIN: Epon 828/CL
FINISH: A-1100

Properties of Bar Moldings	Method Used to Remove 630 Textile Size From Glass Tape			
	Solvent Extraction Followed by Enzyme Digestion*		Standard Heat Cleaning Batch Method	
	"E" Glass	YM31A Glass	"E" Glass	YM31A Glass
Dry Flexural Strength, 10^3 psi	52.4	60.5	57.7	72.1
Dry Flexural Modulus, 10^6 psi	2.75	3.83	2.81	3.83
Wet Flexural Strength, 10^3 psi	49.9	58.2	50.5	60.7
Wet Flexural Modulus, 10^6 psi	2.66	3.56	2.60	3.51
Dry Compressive Strength, 10^3 psi	39.6	40.5**	39.3	42.2
Dry Compressive Modulus, 10^6 psi	3.46	4.95**	3.51	4.78
Wet Compressive Strength, 10^3 psi	32.3	34.3	35.6	33.5
Wet Compressive Modulus, 10^6 psi	3.32	4.34	3.21	4.58
Glass By Volume %	39.0	40.2	39.2	40.6

All wet properties were measured after a 2-hour boil in distilled water.
*After the chemical desize, the material was treated at 650°F for 15 hours.
**These values represent a test made on a single bar. A second bar was damaged when removed from the mold. All other values are averages of two tests per property.
***Values represent an average of four determinations.

Wet or dry compressive strength data for both glasses show no significant differences between the range of glass contents studied.

As was expected, YM31A glass reinforced bars exhibited better dry and wet flexural properties and compressive moduli, than did "E" glass for both methods of size removal.

Resin-Finish Systems

The effects of finish variables on laminate properties have been systematically investigated using three-fourths inch YM31A tape (30 ends) and the bar molding technique. The object was to define resin-finish systems that give wet flexural strengths at least equal to those obtained with "E" glass. Resin-finish combinations which were studied are presented in Table XVI.

Paraplex P-43 Polyester Resin

Part of the work done with Paraplex P-43 resin using A-172 finished material was presented in the section "Surface Treatments for YM31A Glass" which begins on page 93. Studies of two other finishes, Volan A and Garan, using P-43, were also completed. A balanced sixteen-run experiment was designed to study the following variables:

Experimental Design 2^{8-4} (e.g., Eight variables at 2 levels. The experiment contained 2^{8-4} or 16 moldings.)

Variables	Variable Levels	
	Level 1	Level 2
Glass	"E"	YM31A
Sample Boiled in Water Prior to Finishing	No	Yes
Finish Used	Garan	Volan
Finish Concentration	1%	2%
Finish Bath Temperature	80°F	120°F
Duration of Finish Cure	10 minutes	20 minutes
Water Rinse After Finish Application	No	Yes

Laminates were prepared using the bar molding technique. Molding conditions were the same as described under chemical desizing systems. Heat cleaned (standard cycle) tape was used for all bars. The method used for preparing each specimen is presented in Table XVII.

The effects of the critical finish variables on the wet flexural strength are summarized in Table XVIII. Test data are presented in

TABLE XVI

RESIN FINISH COMBINATIONS
STUDIED WITH YM31A GLASS FIBERS

		Finishes				
		Volan A	A-1100	Garan	A-172	T-31
Resins	P-43		N.A.			N.A.
	Epon 828			N.A.	N.A.	N.A.
	Vibrin 136A		N.A.			N.A.
	CTL 91-LD			N.A.	N.A.	N.A.
	DC 2106	N.A.	N.A.	N.A.	N.A.	
N.A. = Not applicable for this study						

TABLE XVII

MOLDING CONDITIONS FOR BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS TAPE

RESIN: Paraplex P-43
FINISHES: Volan A and Garan

Specimen Number	Time of Finish Cure (Minutes)	Prewash of Glass	Finish	Finish Conc. %	Temp. of Finish Cure °F	Glass	Afterwash of Glass	Temp. of Finish Bath °F
1	10	No	Garan	1	250	"E"	No	80
2	20	No	Garan	1	300	YM31A	Yes	80
3	10	Yes	Garan	1	300	YM31A	No	120
4	20	Yes	Garan	1	250	"E"	Yes	120
5	10	No	Volan	1	300	"E"	Yes	120
6	20	No	Volan	1	250	YM31A	No	120
7	10	Yes	Volan	1	250	YM31A	Yes	80
8	20	Yes	Volan	1	300	"E"	No	80
9	10	No	Garan	2	250	YM31A	Yes	120
10	20	No	Garan	2	300	"E"	No	120
11	10	Yes	Garan	2	300	"E"	Yes	80
12	20	Yes	Garan	2	250	YM31A	No	80
13	10	No	Volan	2	300	YM31A	No	80
14	20	No	Volan	2	250	"E"	Yes	80
15	10	Yes	Volan	2	250	"E"	No	120
16	20	Yes	Volan	2	300	YM31A	Yes	120

Appendix, Table LIV. The variables of finish concentration, finish bath temperature, and time and temperature of finish cure had no effect on wet flexural strength over the range studied and are not included in Table XVIII.

TABLE XVIII

THE EFFECTS OF FINISH VARIABLES
ON THE WET FLEXURAL STRENGTHS OF BAR MOLDINGS
RESIN: PARAPLEX P-43

		Wet Flexural Strength at 10^3 psi			
		"E" Glass		YM31A Glass	
		Garan	Volan A	Garan	Volan A
Prerinse	After-Rinse	50.0	47.7	39.0	45.9
	No After-Rinse	49.2	42.4	38.3	40.8
No Prerinse	After-rinse	48.1	45.7	37.1	44.0
	No After-Rinse	47.3	40.5	36.4	38.9
The standard deviation of presented values is 0.95 x 10^3 psi.					

Discussion of Results. The following conclusions can be drawn from the presented data:

1. No combination of finish application methods was found which would give YM31A laminate strengths equal to those for "E" glass laminates.

2. Effects of prerinsing and after-rinsing the tape were much more critical with Volan A than with Garan. Since these effects were additive with both glass types, any increase in "E" glass was also obtained with YM31A glass. It is believed that increases in strength from the rinses were the result of removal

of salts and unreacted finish compounds from the glass surface.

3. For YM31A glass, Volan A gives higher flexural strengths than Garan finish. The reverse is true for "E" glass.

It is believed that Conclusion 3 indicates that finish-glass "bonding" does occur with YM31A glass as well as with "E" glass, but that the physical-chemical nature of the glass surfaces is different in each case.

Epon 828, Epoxy Resin

Volan A and A-1100 Finishes. A balanced sixteen-run experiment was designed to study variations in applying Volan A and A-1100 finishes to "E" glass and YM31A glass tape. The following is a list of variables studied:

Experimental Design: 2^{8-4} (e.g., Eight variables at 2 levels. The experiment contained 2^{8-4} or 16 moldings.)

Variables	Variable Levels Level 1	Level 2
Glass	"E"	YM31A
Glass Prewashed-Deionized Water	No	Yes
Glass Heated at 650°F*	No	Yes
Finish Type	Volan A	A-1100
Finish Concentration	1%	2%
Finish Baths pH	Volan A - 3.0 A-1100 - 5.0	Volan A - 6.0 A-1100 - 11.0
Finish Bath Temperature (Heated for 20 minutes at)	80°F	160°f
Afterwash-Deionized Water	No	Yes

*Glass tape passed through a tubular oven heated to 650°F at 20 feet per minute.

Laminates were prepared using the bar molding technique. Heat cleaned (standard cycle) tape was used for all bars. The method used for preparing each specimen is presented in Table XIX. The molding conditions used were as follows:

Resin:	Epon 828 - catalyzed with 14 pph of CL hardner.
Cure Temperature:	250°F
Cure Time:	One hour
Postcured:	For one hour at 375°F

Only those finishing variables that affected the wet flexural strengths are presented in Table XX. Test data are presented in Appendix, Table LV.

TABLE XIX

MOLDING CONDITIONS FOR BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS

FINISHES: A-1100 and Volan A
RESIN: Epon 828/CL

Specimen Number	Glass	Prewash of Glass	Glass Heated Prior to Finish	Finish conc. (%)	Finish	pH of Finish Bath	Temp. of Finish Bath °F	Afterwash of Glass
1	"E"	No	No	1	Volan A	Low	80	No
2	YM31A	No	No	1	A-1100	High	160	No
3	"E"	Yes	No	1	A-1100	High	80	Yes
4	YM31A	Yes	No	1	Volan A	Low	160	Yes
5	"E"	No	Yes	1	A-1100	Low	160	Yes
6	YM31A	No	Yes	1	Volan A	High	80	Yes
7	"E"	Yes	Yes	1	Volan A	High	160	No
8	YM31A	Yes	Yes	1	A-1100	Low	80	No
9	"E"	No	No	2	Volan A	High	160	Yes
10	YM31A	No	No	2	A-1100	Low	80	Yes
11	"E"	Yes	No	2	A-1100	Low	160	No
12	YM31A	Yes	No	2	Volan A	High	80	No
13	"E"	No	Yes	2	A-1100	High	80	No
14	YM31A	No	Yes	2	Volan A	Low	160	No
15	"E"	Yes	Yes	2	Volan A	Low	80	Yes
16	YM31A	Yes	Yes	2	A-1100	High	160	Yes

TABLE XX

WET FLEXURAL PROPERTIES FOR BAR MOLDINGS
MADE WITH "E" AND YM31A GLASS TAPES
AND EPON 828 RESIN

Glass	Wet Flexural Strength,* 10^3 psi		Wet Flexural Modulus,** 10^6 psi	
	Finished with Volan A	Finished with A-1100	Finished with Volan A	Finished with A-1100
"E"	56.0	57.0	2.72	2.72
YM31A	62.9	70.1	3.66	3.66

*The standard deviation of presented values is 1.20×10^3 psi.
**The standard deviation of presented values is 0.01×10^6 psi.

Discussion of Results. The following conclusions can be drawn from these data:

1. YM31A glass tape reinforced bars showed increased strengths over bars reinforced with "E" glass for both finish systems.
2. A combination of YM31A glass and A-1100 finish gave the highest wet flexural strength.
3. YM31A glass reinforced bars had the best wet flexural modulus.
4. For each glass the wet flexural modulus was independent of finish used.

The results obtained show that Epon 828 resin is more suitable for YM31A glass than polyester resin. A combination of A-1100 finish and Epon 828 gave better strengths for both glass types. This finish was designed specifically for use with epoxy resins.

The high strengths obtained using YM31A glass tape as reinforcement are believed to be a function of the ductility of Epon 828 resin. A more thorough discussion of this phenomenon is presented in the section on "The Behavior of YM31A Glass in Reinforced Plastics" which begins on page 126 of this report.

With Epon 828 molded bars, the only variable that significantly affected wet compressive strength was the glass surface finish. Glass composition was the only variable that significantly affected compressive modulus. The values obtained for both compressive properties are given in Table XXI.

TABLE XXI

WET COMPRESSIVE PROPERTIES OF "E" AND YM31A GLASS BAR MOLDINGS

RESIN: EPON 828/CL

	"E" Glass		YM31A Glass	
	Volan A	A-1100	Volan A	A-1100
Compressive Strength after 2 hour boil, 10^3 psi*	36.3	43.1	36.3	43.1
Compressive Modulus after 2 hour boil, 10^6 psi**	3.19	3.19	4.46	4.46

*The standard deviation of presented values is 0.65 x 10^3 psi.
**The standard deviation of presented values is 0.10 x 10^6 psi.

The wet compressive strengths indicate that A-1100 finish is better suited than Volan A finish for Epon 828 or epoxy resins. Since A-1100 finish was specifically designed for epoxy resins, the difference is not unexpected. Use of YM31A glass reinforcement did not alter the compressive strengths from those obtained with "E" glass. This probably means that the wet compressive strengths are dependent upon the resin-finish bond.

Compressive modulus was affected by the glass type. YM31A glass tape reinforced bar moldings gave higher compressive moduli than did use of "E" glass reinforcement. This difference is definitely caused by the difference in glass modulus.

The results obtained for glass content, ignition loss, and specific gravity are shown in Table XXII.

The bar moldings reinforced with YM31A glass tape had the higher specific gravity. (YM31A glass does have a higher specific gravity than "E" glass - 2.89 to 2.54.)

These results also show that moldings made with YM31A glass contained more glass by volume than moldings with "E" glass. The data in Table XXII, which show a difference of 1.6%, are typical of our experiments with woven tape. Inherently there was more variation in YM31A glass tape. Probably slightly coarser yarns, which were chosen for the warp, caused the small difference.

TABLE XXII

IGNITION LOSS, GLASS BY VOLUME, AND SPECIFIC GRAVITY FOR "E" GLASS AND YM31A GLASS BAR MOLDINGS MADE WITH EPON 828 RESIN

Glass	Ignition Loss* %	Glass by Volume** %	Specific Gravity***
"E"	42.5	38.4	1.70
YM31A	38.0	40.0	1.86

*The standard deviation of presented values is 0.25 per cent.
**The standard deviation of presented values is 0.28 per cent.
***The standard deviation of presented values is 0.01 per cent.

Additional moldings were made with Epon 828 epoxy resin with both "E" glass and YM31A glass tape at different levels of glass by volume. The wet flexural and compressive strengths obtained are presented in Figures 1 and 2. Test data are presented in Appendix, Table LVI.

These data show that for a one per cent increase in glass by volume the following increases in strength would be expected.

Glass	Wet Flexural Strength, 10^3 psi	Wet Flexural Modulus, 10^6 psi	Wet Compressive Strength, 10^3 psi	Wet Compressive Modulus, 10^6 psi
"E"	1.0	0.1	0.4	0.2
YM31A	1.5	0.1	0.4	0.1

These data are approximations but they do indicate that the higher glass contents obtained with YM31A glass do affect our results to a degree. On a comparable volume basis with "E" glass data, the effect would be to lower the strength values for the YM31A glass reinforced bars by a small amount.

CTL 91-LD: Phenolic Resin

Volan A and A-1100 Finishes. An eight-run balanced experiment was designed to study variations in applying Volan A or A-1100 finishes to heat cleaned (standard cycle) glass tape. The following is a list of variables studied using "E" or YM31A glass tape.

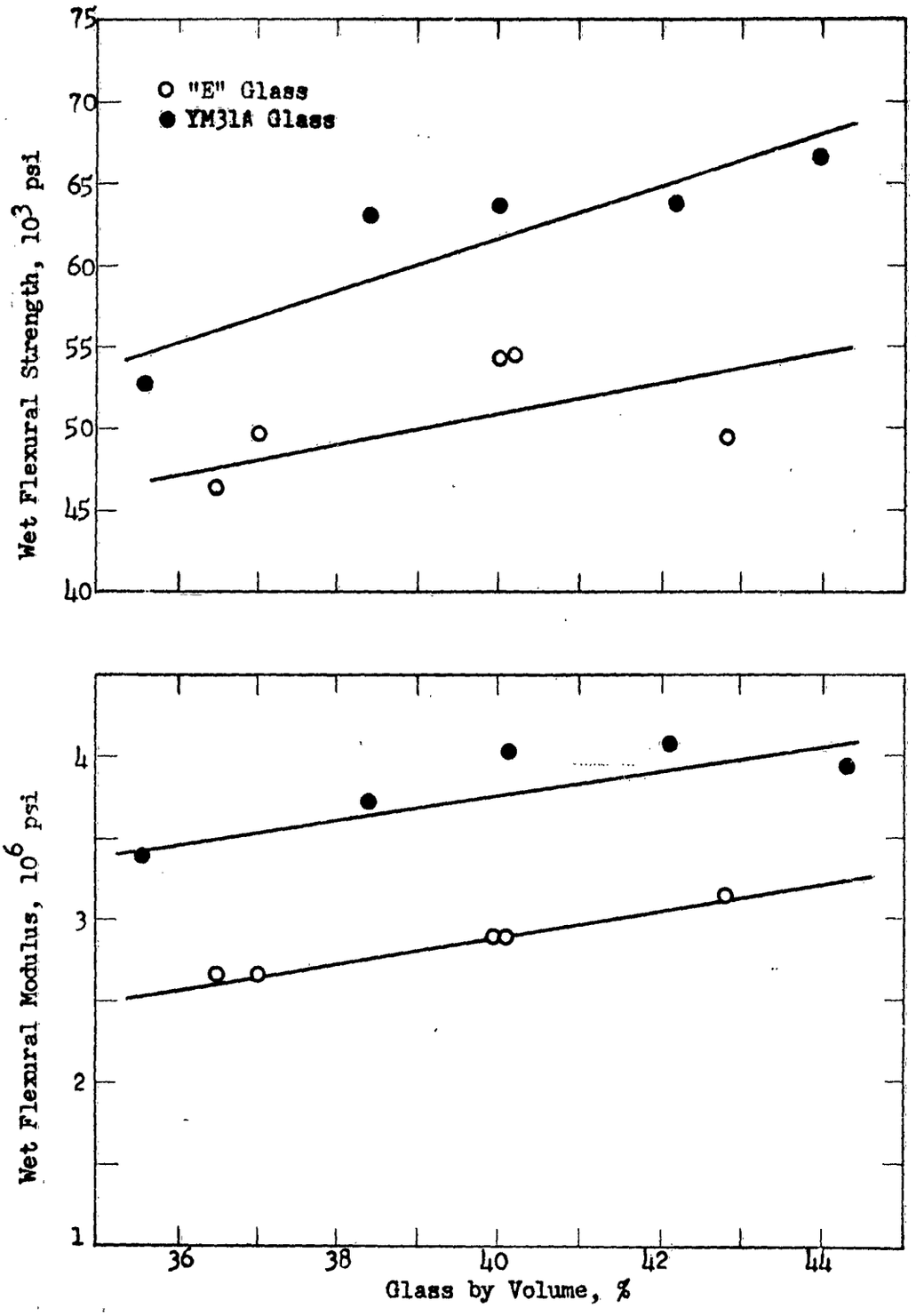


Figure 1 - Wet Flexural Properties of "E" and YM31A Glass Tape Reinforced Laminates
Finish: A-1100 **Resin: Epon 828/CL**

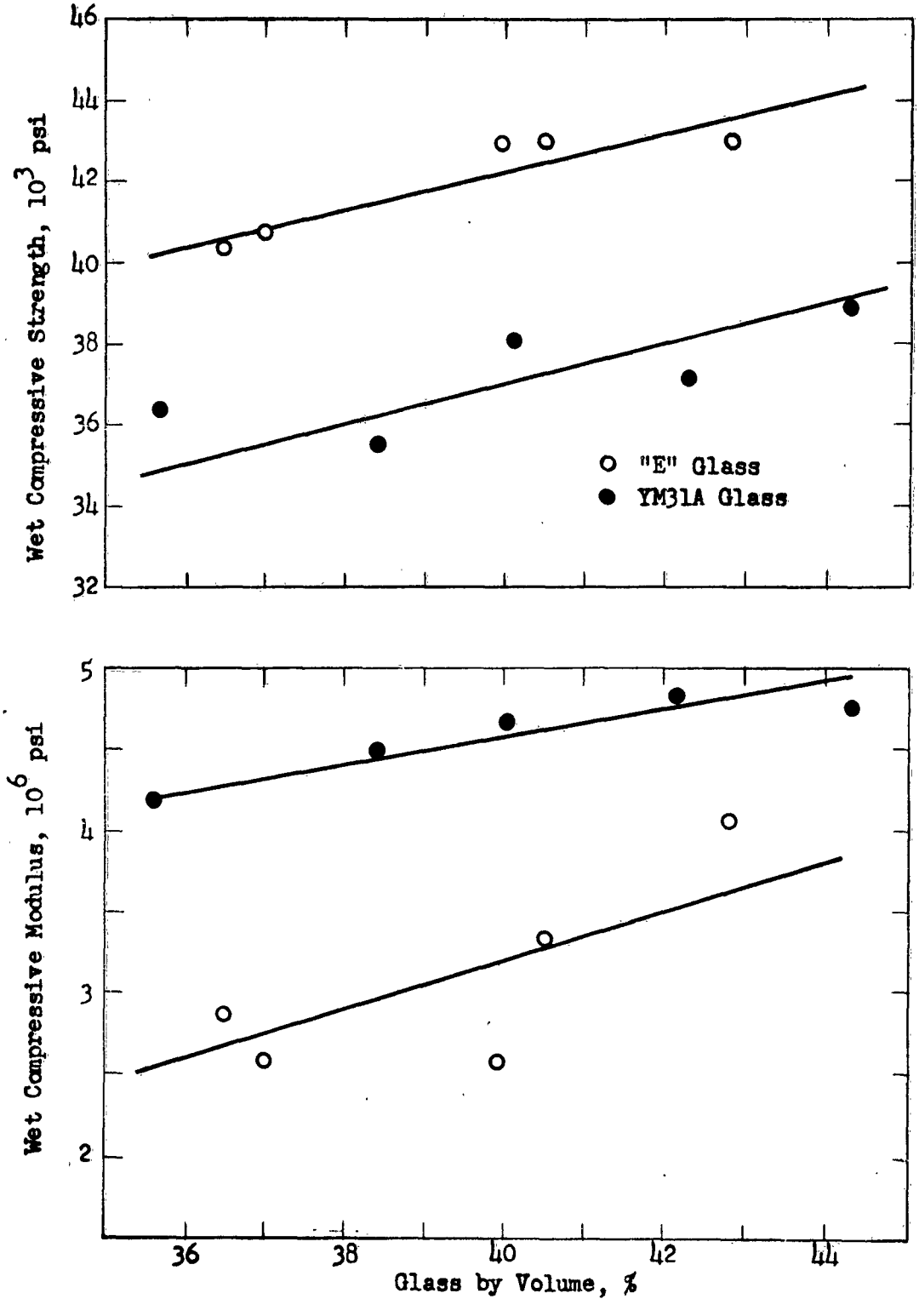


Figure 2 - Wet Compressive Properties of "E" and YM31A Glass Tape Reinforced Laminates

Finish: A-1100 Resin: Epon 828/CL

Experimental Design: 2^{7-4} (e.g., Seven variables at 2 levels. The experiment contained 2^{7-4} or 8 moldings.)

	Variable Levels	
	Level 1	Level 2
Glass	"E"	YM31A
Glass Prewashed-Deionized water	No	Yes
Finish Concentration	1%	2%
Finish	Volan A	A-1100
pH Finish Bath	Low Volan A - pH 3.0 A-1100 - pH 5.0**	High Volan A - pH 6.0* A-1100 - pH 11.0
Finish bath heated for one-half hour at	80°F	120°F
Glass Afterwashed-Deionized water	No	Yes

*Neutralized with ammonium hydroxide.
**Acidified with acetic acid.

Nineteen ply laminates were prepared using the bar molding technique. Impregnating and molding conditions used were as follows:

Impregnating Conditions:

Resin:	CTL 91-LD
Resin Content:	43.6%
Volatile Content:	6.95%
Flow:	20% (using 15 psi at 325°F)

Molding Conditions:

Primary Cure:	20 min at 300°F
Post Cure:	24 hrs at 300°F
	24 hrs at 350°F
	24 hrs at 400°F

The normally light pressure of the bar molding technique with polyester resins was increased by adding two plies of tape and a 0.015 inch shim. The additional pressure when the mold came to stops provided better resin distribution and expelled air entrapped between the plies.

Treatment combinations used for preparing each specimen are presented in Table XXIII.

Physical properties of bar moldings, after data analysis, are presented in Tables XXIV, XXV, AND XXVI. Only those variables are presented

TABLE XXIII

MOLDING CONDITIONS FOR BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS

RESIN: CTL 91-LD
FINISHES: VOLAN A AND A-1100

Specimen Number	Glass	Glass Prewash	Finish	Finish Conc. (%)	pH of Finish Bath	Finish Bath Heated for 1/2 hr at	Afterwash of Glass
1	"E"	No	Volan A	1	Low	80°F	No
2	YM31A	No	A-1100	1	High	120°F	No
3	"E"	Yes	A-1100	1	High	80°F	Yes
4	YM31A	Yes	Volan A	1	Low	120°F	Yes
5	"E"	No	Volan A	2	High	120°F	Yes
6	YM31A	No	A-1100	2	Low	80°F	Yes
7	"E"	Yes	A-1100	2	Low	120°F	No
8	YM31A	Yes	Volan A	2	High	80°F	No

which significantly affected the wet properties, according to statistical analysis. Test data for all molded specimens are presented in Appendix, Table IVIII.

TABLE XXIV

WET FLEXURAL STRENGTHS OF BAR MOLDINGS
REINFORCED WITH "E" OR YM31A GLASS TAPE

Resin: CTL 91-LD
Finishes: Volan A or A-1100

Property	Wet Flexural Strength, 10^3 psi After a 2 Hour Boil			
Glass	"E"		YM31A	
Finish	Volan A	A-1100	Volan A	A-1100
No Afterwash	58.2	57.0	60.5	78.7
Afterwashed	69.9	66.1	70.6	84.9
Standard deviation of presented values is 1.42 x 10^3 psi.				

Discussion of Results. After washing the finished material was beneficial for both glasses. Residual salts, present on the glass surface after finishing were probably removed by the afterwash.

No significant difference in strength was noted between laminates reinforced with "E" or YM31A glass tape using Volan A finish.

The results obtained indicate that A-1100 finished YM31A glass reinforcement was superior to "E" glass with CTL 91-LD phenolic resin. The increase in strength noted should be expected, since the A-1100 silane finish was designed for specific use with epoxy and phenolic resins. Phenolic resins are similar to epoxy resins in that they have higher bonding power than most polyesters. Phenolic resins not only bond to the finish but also to the glass surface.

TABLE XXV

WET FLEXURAL MODULI OF BAR MOLDINGS REINFORCED WITH "E" OR YM31A GLASS TAPE

Resin: CTL 91-LD
Finishes: Volan A or A-1100

	Wet Flexural Modulus, 10^6 psi, after a 2 hr boil	
Glass	"E"	YM31A
Wet Flexural Modulus x 10^6 psi	3.43	4.91
Glass By Volume (%)	50.5	52.5
Standard deviation of presented values is 1.42 x 10^3 psi.		

YM31A glass reinforcement increased the wet flexural modulus over that obtained with "E" glass. Modulus values shown are higher than any obtained previously for both glasses and probably are a result of the higher glass contents. The finishes used did not significantly affect the flexural modulus of bars reinforced with either glass.

TABLE XXVI

PHYSICAL PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" OR YM31A GLASS TAPE

Resin: CTL 91-LD
Finishes: Volan A or A-1100

Glass	"E"	YM31A
Glass by Volume (%)*	50.5	52.5
Ignition Loss (%)**	31.1	26.6
Specific Gravity***	1.87	2.06
*Standard deviation of presented values is 0.98%. **Standard deviation of presented averages is 0.58%. ***Standard deviation of presented averages is 0.03%.		

YM31A glass reinforced bars contained more glass and have a higher specific gravity than bars reinforced with "E" glass.

DC 2106: Silicone Resin

T-31 Finish. An experiment was designed to study variations in conditions for applying Dow Corning T-31 finish to "E" and YM31A glass tape using DC-2106 silicone resin. All moldings were made using the bar molding technique. Several variations in molding were attempted in order to obtain bars acceptable for testing. Each variation was designed to apply successively more pressure to the molding. The strength values obtained could not be analyzed mathematically because the balance of the experiment was destroyed when two specimens were damaged. The remaining test data are presented in Table XXVII.

TABLE XXVII

FLEXURAL PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" OR YM31A GLASS TAPE

Resin: DC-2106 Silicone Resin
Finish: Dow Corning T-31

Specimen Number	Glass	Wet Flexural Strength 10^3 psi after a 2 hr boil	Wet Flexural Modulus 10^6 psi after a 2 hr boil	Specific Gravity
1	"E"	27.6	3.00	1.86
2	YM31A	22.7	4.72	2.14
3	"E"	26.8	2.94	1.91
4	YM31A	10.1	1.98	2.06
5	"E"	30.2	3.48	1.88
*6	YM31A	--	--	--
7	"E"	28.5	3.04	1.80
8	YM31A	9.5	2.10	2.15

*Specimens were damaged upon removal from the mold.

Discussion of Results. Even though the test data were not analyzed mathematically, a trend was detected. This trend indicated that "E" glass was a superior reinforcement to YM31A glass for DC-2106 silicone resin. While the strengths of all DC-2106 bars tested were extremely low, in comparison to other resin-glass systems studied, they were consistent with results obtained during Supplement I of this contract.

The low values obtained with YM31A glass may be explained on the basis that use of a higher modulus reinforcement requires good resin-finish-glass bonding. DC-2106 silicone resin probably does not have as high a bonding power as does Epon 828 epoxy resin, nor is it as strong. Apparently, a combination of low bonding power and low resin strength has a deleterious effect on strength of laminates reinforced with YM31A glass.

Vibrin 136A: Polyester Resin

A-172, Garan and Volan Finishes. Attempts to mold Vibrin 136A resin bars, reinforced with "E" or YM31A glass tape were unsuccessful. During post cure, all bars reinforced with glass tape were completely "blistered." Work done under Phase III has shown that Vibrin 136A polyester resin can be post cured without formation of large visual blisters provided that parallel strand reinforcement is used. In order to determine the behavior of YM31A glass yarn when imbedded in Vibrin 136A resin, 12 bar moldings were made. These moldings were made using "E" or YM31A glass yarn finished with A-172, Garan, or 08 treatment. The molding conditions used were as follows:

Resin:	Vibrin 136A
Catalyst:	0.15% Tertiary butyl perbenzoate
Cure:	2 hours at 250°F
Post Cure:	1 hour at 400°F
	1 hour at 450°F
	3 hours at 500°F

The results obtained for all properties are presented in Table XXVIII.

Discussion of Results. "E" glass appears to be a superior reinforcement to YM31A glass, even though the results obtained are not consistent within themselves. In some instances, wet tested samples exhibited improved strength, while in others, the reverse was true. The erratic nature of the test data can be related to the matrix material. Vibrin 136A is an extremely sensitive resin during post cure, because minute blisters may form which cannot be detected visually. Formation of these blisters or delamination destroys the homogeniety of the reinforced plastic bar. Within the same molding, differences as large as 38.6×10^3 psi have been detected. Even though strict temperature control was maintained throughout the post cure, large differences in strength were obtained. The importance of temperature control during post cure cannot be over emphasized.

The Behavior of YM31A Glass in Reinforced Plastics

In order to understand and explain the mechanism of reinforcement using high modulus glass in molded parts, additional experiments were

TABLE XXVIII

PROPERTIES OF BAR MOLDINGS REINFORCED WITH PARALLEL STRAND "E" OR YM31A GLASS YARN

Finishes: A-172, Garan, or 08 Treatment
Resin: Vibrin 136A

	A-172		Garan		08	
	"E"	YM31A	"E"	YM31A	"E"	YM31A
Dry Flexural Strength 10^3 psi	238.7	168.7	224.1	194.0	230.7	202.8
Dry Flexural Modulus 10^6 psi	7.37	10.4	8.18	10.7	8.18	10.5
Wet Flexural Strength 10^3 psi after 2 hr boil	251.5	153.2	232.8	235.4	234.5	177.1
Wet Flexural Modulus 10^6 psi after 2 hr boil	8.35	10.1	8.18	10.7	8.15	9.72
Ignition Loss (%)	20.0	17.5	21.0	17.5	20.5	17.6
Glass by Volume (%)	66.0	66.7	65.3	66.8	66.4	66.1
Specific Gravity	2.10	2.34	2.11	2.32	2.13	2.32

performed for this phase of the work. Some resins used were not originally specified for this phase but were chosen on the basis of unique properties. By properly selecting these resins, it was possible to radically vary the properties of the molded parts.

Resin and Glass Variations

Paraplex P-13 was blended with Paraplex P-444 to vary the properties of the resulting resins. Paraplex P-444 was chosen for its high flexural strength and modulus, which are 17,500 psi and 0.63×10^6 psi respectively. The properties of Paraplex P-13 are unique in that this resin has an indeterminate flexural strength and a flexural modulus of only 6,400 psi. Blends of these two resins were molded with 08 treated "E" and YM31A glass yarn (approximately 150 x 1/0's) and Volan A

finished "E" and YM31A glass tape as the reinforcement.

A stock solution of Paraplex P-444 was prepared containing 80 per cent resin and 20 per cent styrene by weight. Portions of this stock solution were diluted with P-13 and catalyzed with one per cent benzoyl peroxide according to the following formulations:

1. 50 per cent Paraplex P-444
   50 per cent Paraplex P-13

2. 70 per cent Paraplex P-444
   30 per cent Paraplex P-13

3. 100 per cent Paraplex P-444
   0 per cent Paraplex P-13

The reinforcement was impregnated with resin and the bar was cured for 20 minutes at 320°F.

The dry flexural strengths obtained for parallel strand reinforced moldings are presented in Figure 3 and for tape in Figure 4. Test data are presented in Appendix, Table LVIII and in the following discussion of results.

Discussion of Results.

1. At equal percentage glass by volume the flexural strength is very dependent upon the resin used. The moldings made with a 50/50 blend of Paraplex P-444 and Paraplex P-13 had the poorest flexural strengths. The "E" glass strand reinforced molding with 100 per cent Paraplex P-444 resulted in a 166 per cent increase in strength over the bar molded with a 50/50 resin blend.

2. The modulus of the composite structure is almost entirely dependent upon the type of reinforcement used. A comparison of the flexural moduli of YM31A yarn, at 53 per cent and 68 per cent glass by volume, to "E" glass yarn at 68 per cent glass by volume, indicates that the reinforcement contributes most to the modulus of the composite structure. The resin does contribute its modulus to the composite structure, but the effect is small. With 100 per cent P-444, the use of YM31A (at 68 per cent glass by volume) in the molded bar increased the flexural modulus by 48 per cent over that obtained with "E" glass.

3. The results for tape reinforced bars also show the same strength and modulus relationships, but the effects are not so pronounced. This is a result of lower glass contents and the fact that in the tape reinforced bars only half of the glass is oriented in the direction of applied stress.

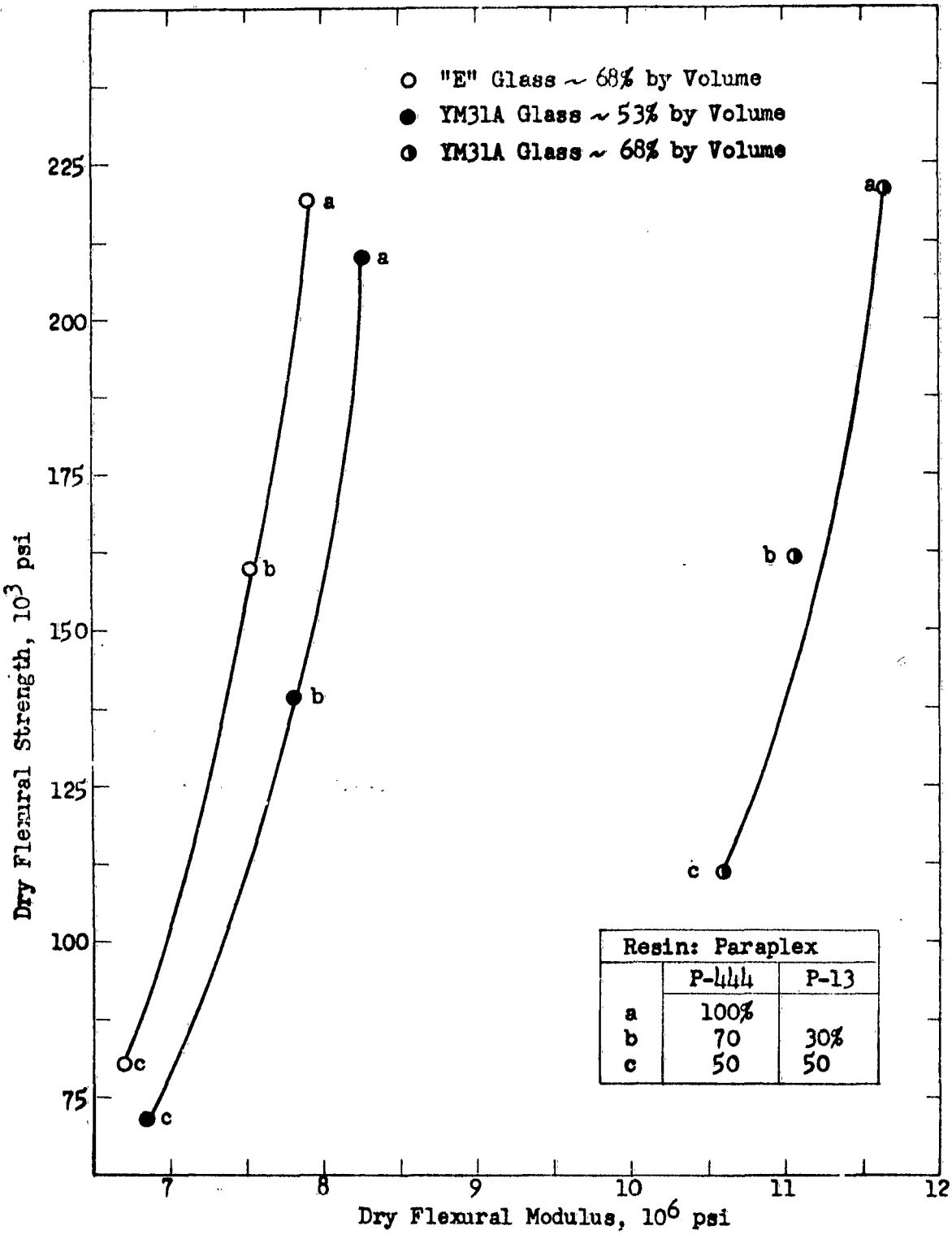


Figure 3 - The Relationship Among Laminate Modulus, Resin Used and Laminate Dry Flexural Strength for Parallel Strand Reinforced Moldings

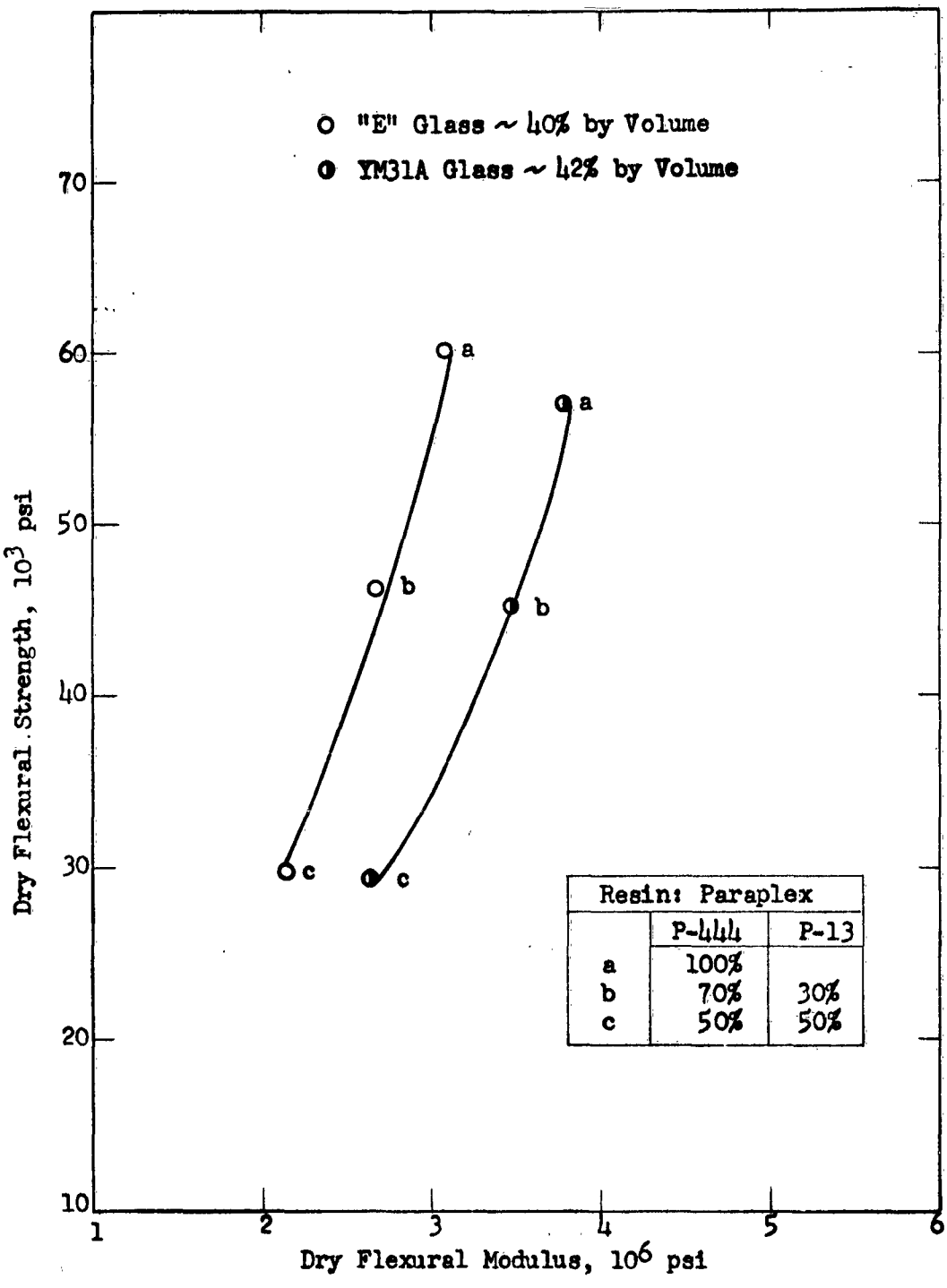


Figure 4 - The Relationship Among Laminate Modulus, Resin Used and Dry Flexural Strength for Tape (128 Weave) Reinforced Moldings

4. YM31A glass tape reinforced moldings gave slightly lower strengths than those made with "E" glass. Further work to investigate this phenomenon is discussed in this section.

Based upon the preceeding results, we believe that resins for use in reinforced plastics should be chosen by careful examination of their physical properties. The dry strengths of glass reinforced plastics (at equal glass loadings) are dependent upon the weakest component in the structure which is the resin.

Effect of the Flexural Modulus of the Polyester Resin

In the previous section the importance of the flexural strength and modulus of the cast unreinforced resin was pointed out. Additional bar moldings were made with "E" or YM31A glass yarn with Paraplex P-43 and Paraplex AP-174. These resins were chosen because they have nearly identical strengths but different flexural moduli, so that it is possible to relate strength of bar moldings to the finish and resin modulus. Specifically, the physical properties of both resins in the cast, unreinforced condition are as follows:

	Flexural Strength x 10^3 psi	Flexural Modulus x 10^6 psi
Paraplex P-43	17.5	0.62
Paraplex AP-174	17.4	0.734

Flexural properties obtained for parallel strand bar moldings with different finishes are presented in Table XXIX.

Discussion of Results. In a laminate made with Paraplex AP-174 resin and Garan finished "E" glass as the reinforcement, strengths were obtained which were 19 per cent higher than identical moldings made with Paraplex P-43. Using Garan finished YM31A glass, the reverse was true. Apparently, there must be an interaction between resin modulus, glass modulus, and type finish. When YM31A yarn with 08 treatment was used to reinforce Paraplex AP-174, a flexural strength of 268.3 x 10^3 psi was obtained. We believe that a system which is composed of (1) high flexural strength and modulus resin, (2) parallel strand YM31A glass, and (3) good resin-finish-glass bonds, resulted in the high strength. YM31A glass as a reinforcement, a more rigid glass, requires better resin-finish glass bonds for optimum performance in reinforced plastics.

Use of 830 sized YM31A glass resulted in the lowest flexural strengths. Probably, the ingredients, other than the finish present in the 830 size formulation as applied at forming, inhibited formation of good resin-finish-glass bonds. In addition, 830 size contains a silane finish which does not form good bonds between the resin and YM31A glass. More work should be done to further investigate these findings.

TABLE XXIX

FLEXURAL PROPERTIES OF "E" AND YM31A GLASS PARALLEL STRAND REINFORCED BAR MOLDINGS

Glass	Finish	Resin	Dry Flexural Strength, 10^3 psi	Dry Flexural Modulus, 10^6 psi	Wet Flexural Strength, 10^3 psi	Wet Flexural Modulus, 10^6 psi	Ignition Loss (%)	Glass by Volume (%)
"E"	Garan	Paraplex P-43	229.8	7.54	--	--	18.7	--
YM31A	Garan	Paraplex P-43	244.5	10.76	--	--	15.6	--
"E"	Garan	Paraplex AP-174	262.3	7.73	--	--	18.6	--
YM31A	Garan	Paraplex AP-174	232.9	10.03	--	--	17.6	--
YM31A	08 Treatment	Paraplex AP-174	268.3	10.8	209.0	10.7	17.6	65.5
YM31A	830 Size*	Paraplex AP-174	130.9	10.0	79.4	8.28	17.9	64.0

*Polyester compatible size - silane.

Resin-Finish-Glass Bond

In the section above and in previous work with polyesters, using woven material as the reinforcement, YM31A glass did not function as well as "E" glass in laminates. To determine if finish bonds form, a simple experiment was performed using parallel yarn reinforcements. This experiment consisted of the following variables:

Variables	Variable Levels 1	vs	2
Glass	"E"		YM31A
Glass Surface	Bare Heat Cleaned		Heat Cleaned, A-1100 Finished

Two packages of heat cleaned "E" and YM31A glass yarn were soaked over-night in a 0.30 per cent water solution of A-1100 which was acidified to a pH of 5 with acetic acid. The yarn was removed, dried at room temperature, and then dried for an additional four hours at 220°F.

Bars were molded of parallel yarns using Epon 828 resin catalyzed with 14 pph of metaphenylene diamine (CL hardner). These bars were molded at 250°F for one hour. None of the bars in this experiment were post cured.

Wet flexural strength is one of the better measurements for determining variations in resin or finishes. All bars were tested for flexural strength after a two-hour boil in distilled water. The results obtained are presented in Table XXX.

TABLE XXX

DETERMINATION OF GLASS-FINISH-RESIN BOND USING EPON 828/CL ON A-1100 FINISHED AND BARE "E" AND YM31A GLASS REINFORCEMENT

Glass Surface	Glass	Wet Flexural Strength 10^3 psi	Wet Flexural Modulus 10^6 psi	Glass by Volume (%)
Bare - Heat Cleaned	"E"	168.4	6.72	61.0
Bare - Heat Cleaned	YM31A	196.3	10.26	65.4
Heat Cleaned A-1100 Finished	"E"	202.9	6.90	60.4
Heat Cleaned A-1100 Finished	YM31A	246.6	10.34	64.9

Discussion of Results. After comparing flexural strengths, moduli and glass contents, it is apparent that YM31A glass molded bars were stronger, stiffer, and contained more glass. The difference in glass content by itself could not have accounted for such large differences in strength. Much of the strength difference is believed to have been caused by the different glass-surface system with this particular resin, Epon 828. Load deflection curves for each finish-glass combination with Epon 828 resin are presented in Figure 5.

Examination of these load deflection curves revealed some interesting facts. Moldings made with bare heat cleaned glass did not behave the same as those with A-1100 finished glass. The bare glass reinforced bar showed a definite yield point before ultimate load was reached. The plot for finished glass reinforced bars was a straight line up to failure.

A measurement of finish bond strength was obtained by measuring the amount of work absorbed by the test specimen as it was loaded during the flexural test. The simplest way to measure the work done was to measure the area under the load deflection curve with a planimeter. Only the area under the load deflection curve which behaves according to Hooke's law was measured. (The area measured was under the straight line portion of the load deflection curve below yield point.) The ordinate and abicissa of the load deflection chart were expressed in pounds and inches deflection, respectively. The area or work done was, therefore, expressed in inch-pounds. Data are given in Table XXXI.

TABLE XXXI

MEASUREMENT OF WORK DONE TO RUPTURE FOR BARE AND A-1100 FINISHED "E" AND YM31A GLASS WITH EPON 828

Glass Surface	Glass	Work done to rupture measured under the load deflection curve to the Yield Point*	Per cent increased in work done to rupture
Bare Heat Cleaned	"E"	14.35 inch-pounds	---
A-1100 Finished Heat Cleaned	"E"	57.5 inch-pounds	306
Bare Heat Cleaned	YM31A	13.60 inch-pounds	---
A-1100 Finished Heat Cleaned	YM31A	50.00 inch-pounds	268

*The areas under two load deflection curves for each condition were measured and the results were averaged.

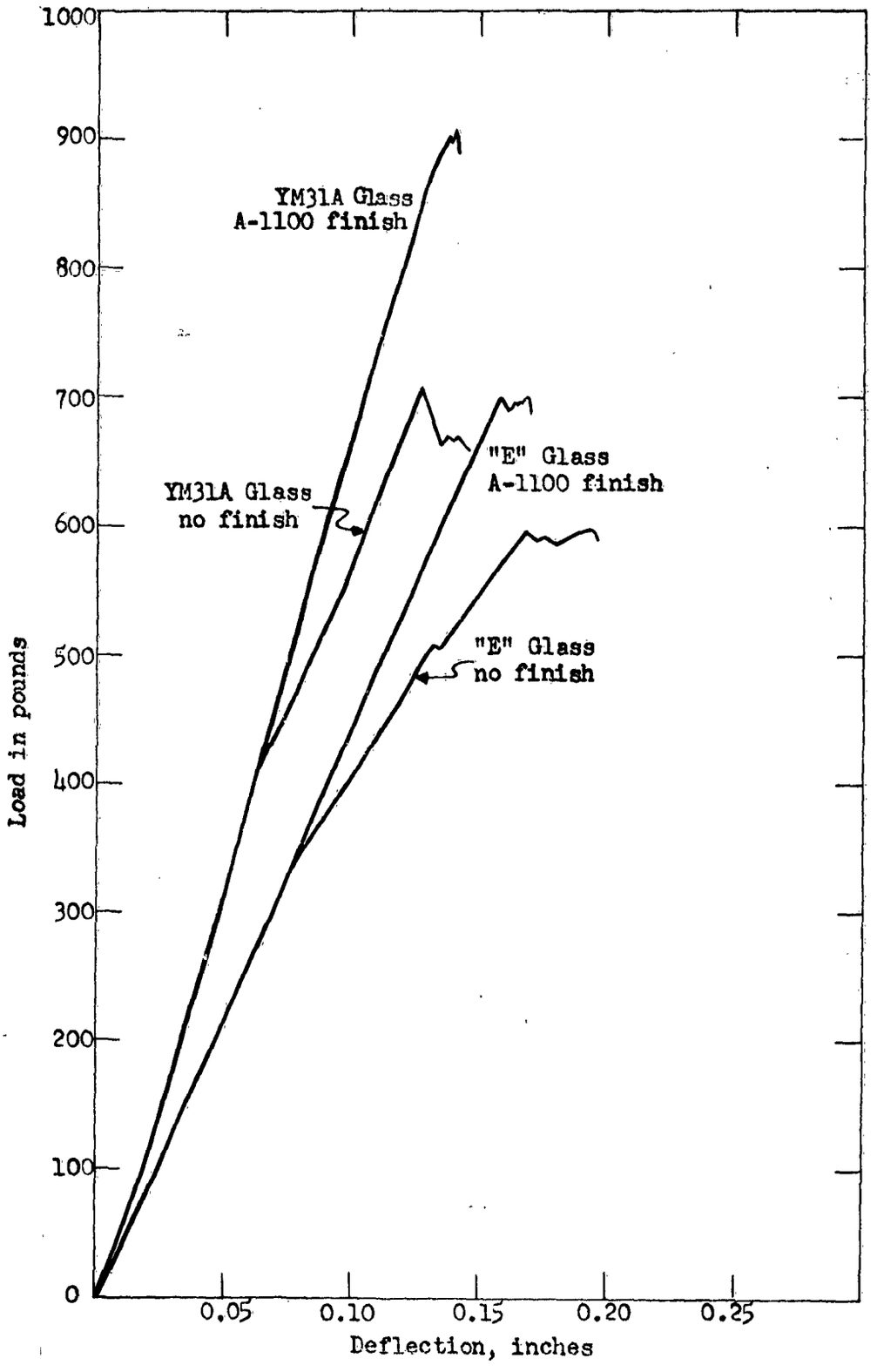


Figure 5 - Load Deflection Curves for Moldings made with Epon 828/CL Epoxy Resin

The presence of a finish definitely increased the ability of the test specimen to absorb work before rupture and enabled the test specimen to behave homogeneously during the loading cycle.

It has been shown in the previous section that resin variation influences dry test properties. Here, influence of the finish is definitely noted when specimens are tested in the wet state. The flexural test is a good measurement for testing specimens; however, at equal glass loadings the wet strength obtained is dependent upon the type of resin and the type of finish.

Strengths of YM31A and "E" Glass Greige Yarns.

Another phenomenon noted in the flexural strength data presented in Table XXX was that YM31A glass reinforced bars showed increased strength over bars reinforced with "E" glass. A difference in glass content may have caused some increase in strength, but not all of the difference noted. Specifically, A-1100 finished YM31A glass with Epon 828 resin showed a 43.7×10^3 psi increase in flexural strength over A-1100 finished "E" glass. Several yarn strength tests were made to determine if any difference exists between the two glasses. The results obtained for tensile strength, toughness, and overhand loop knot strength are presented in Table XXXII.

Since two of the tests used are uncommon, a brief description of each is presented.

Yarn Toughness Test. The term toughness test is actually a misnomer. This test was designed to test the toughness of plastics coatings on coated yarns, not the toughness of yarns. This test consists of draping yarn test sample over a rod (1/4, 1/8, or 1/32 inch diameter) and loading the yarn at both ends as the rod remains stationary.

The test measures a combination of yarn flexural and tensile strength. The initial portion of the applied load is required to bend the yarn around the rod. This portion of the test is a measurement of the yarn flexural strength. The remainder of the applied load is required to rupture the yarn in tension.

Knot Strength Test. The knot strength test is a measure of the tensile strength of a yarn with an overhand knot tied in it. This test gives an indication of the brittleness of the yarn.

Discussion of Results.

Yarn Tensile Test. The results obtained indicate no difference between glasses.

TABLE XXXII

GREIGE YARN PROPERTIES FOR "E" AND YM31A GLASS

	Tensile Strength				Yarn Toughness						Yarn Knot Test	
	YM31A G527 4/0	ECG 150 1/0	YM31A G527 4/2	ECG 600 4/2	YM31A 1/4" Rod	G527 1/8" Rod	4/2 1/32" Rod	ECG 1/4" Rod	600 1/8" Rod	4/2 1/32" Rod	YM31A G527 4/2	ECG 600 4/2
Load Expressed in Pounds	3.9	4.1	7.6	7.7	16.9	16.8	12.8	15.4	13.9	9.3	0.37	0.77
Estimate of Std. Deviation	0.31	0.42	0.36	0.28	0.73	0.43	2.76	1.29	1.33	1.63	0.02	0.09
Elongation (%)	1.7	2.7	1.8	2.5								
Estimate of Std. Deviation	0.14	0.31	0.06	0.08								

Yarn Toughness Test. YM31A glass yarn is stronger than "E" glass regardless of the rod diameter size. According to a basic strength of material formula $\rho = \frac{EI}{Mb}$, which is used in calculating the radius of curvature, more load is required to bend YM31A glass around a rod than is necessary for "E" glass. Once the yarn was in intimate contact with the rod surface, it was loaded in tension. Since both yarns have nearly identical tensile strengths, the differences shown could be caused by the moduli of the materials. Other factors may also influence the data such as abrasion, friction, etc.

Yarn Knot Strength Test. With an overhand knot tied in the test specimen, "E" glass yarn is stronger than YM31A glass. This test is also a measurement of the yarns in bending; however, the radius of curvature in bending becomes too small for either glass to withstand. YM31A glass yarn could not deform to absorb the applied load as well as "E" glass. The constraining force imposed on the glass via the overhand knot caused YM31A glass to fail at a lower applied load. The higher modulus glass yarn is more sensitive to too much constraint than "E" glass. Constrainments imposed in YM31A glass through a knot or weave interlacing may reduce the effectiveness of the glass as a reinforcement.

Investigation of Type Resin and Reinforcement Structure

Yarn knot strength data indicated that YM31A glass is more sensitive to constraint than is "E" glass. Weave interlacings also place a constraint on glass yarns, but not to the extent caused by the overhand knot. To determine if any difference exists between the type resin and reinforcement structure used, an experiment was designed to investigate the following variables:

Variables	Variable Levels 1	vs. 2
Glass	"E"	YM31A
Resin-Finish System	Epon 828/CL A-1100 Finish	Paraplex P-43/BPO Volan A or 08 Treatment
Reinforcement	Tape	Parallel Strand

Specimens for this experiment were prepared using the bar molding technique. The molding temperature and time for both resins were as follows:

Epon 828/CL:	Cured for one hour at 250°F Postcured one hour at 375°F
Paraplex P-43:	Cured for 15 minutes at 230°F No postcure

An analysis of the test data revealed that the structure of YM31A glass reinforcement, parallel strand or tape, had an effect on the wet flexural strengths of bars made with Paraplex P-43 resin. In order to extend this experiment to include information on 128 fabric, 181 fabric, and 143 fabric, additional moldings were made when information from previous work was not available. The following information was used for the comparison of reinforcement structure and resin type:

Paraplex P-43	Data Taken From
128 Style Tape (plain weave) parallel strand.	Initial experiment performed to investigate the effect of reinforcement structure on laminate strength.
181 style fabric (8 harness satin weave	Contract AF 33(616)-5802 Supplement 1 WADD Technical Report 60-24.
143 style fabric* (crowfoot satin weave undirectional fabric)	Molded to complete information on this study.

*90% Paraplex P-43, 10% Styrene, and 1% benzoyl peroxide crystals, cured at 230°F for 15 minutes; 20 psi molding pressure.

Epon 828	Data Taken From
128 Style Tape	Data obtained from heat cleaning vs solvent extraction - enzyme digestion study. (Information obtained was used for they included additional test data where specific values may be of interest)
181 style fabric	Data obtained after completion of the formal program.
143 style fabric**	Molded to complete information on this study.
Parallel strand	Initial experiment performed to investigate the effect of reinforcement structure on laminate strengths.

**Epon 828/14 pph CL hardner; cured at 250°F for one hour; 80 psi molding pressure; post cured for one hour at 375°F.

Information presented is partially complete within itself, that is, each type YM31A reinforcement was compared to an "E" glass control made at the same time.

Since all laminates were tested for wet flexural properties, after a two hour boil, this test was used as a basis for comparison. The results obtained are presented in Figure 6 for Paraplex P-43 resin and in Figure 7 for Epon 828 resin. Specific wet flexural values are presented in Figures 8 and 9 respectively. Test data, including information on dry or wet flexural and compressive properties, are presented in Appendix, Tables LIX and LX.

Paraplex P-43: Polyester Resin

Discussion of Results. The results obtained show the effect of weave interlacings on laminate wet flexural strengths. YM31A glass in 128 and 181 style fabric resulted in wet laminate strengths which were lower than those reinforced with "E" glass in the same fabric styles. Removal of this weave constrainment by use of 143 style fabric or parallel strand reinforcement resulted in strengths of YM31A glass moldings which were higher than "E" glass reinforced moldings.

Polyester resins can form bonds only with the finish present on the glass surface. Paraplex P-43 has a cast resin flexural strength of 17,500 psi and a flexural modulus of 0.61×10^6 psi. This resin probably does not allow stresses to be equally distributed along the tightly woven YM31A glass yarns, because finish bonds lock the reinforcing material within a very brittle resin matrix. The weave interlacings imbedded and locked in resin constraint and, therefore, laminates made with 128 and 181 style fabric and Paraplex P-43 were slightly lower in strength than "E" glass moldings. When Paraplex P-43 was reinforced with 143 style fabric or parallel strand YM31A glass, strengths were obtained which were higher than those obtained with laminates reinforced with "E" glass, primarily through lack of yarn constraint.

Epon 828. Weave constrainment may have an effect on the strengths obtained, but not so severe as that noted with Paraplex P-43. YM31A glass reinforced laminates were always stronger than those reinforced with "E" glass.

Epoxy resins have higher bonding power than most polyesters. It is believed that epoxy resins not only form bonds with the finish but also with the glass surface. Epon 828, catalyzed with mata-phenylene diamine (CL hardner), has a cast resin flexural strength of 17,000 psi and a flexural modulus of 0.43×10^6 psi. A combination of this high bonding power, high strength, and lower modulus enables the stiffer YM31A glass to exhibit better flexural strengths than "E" glass

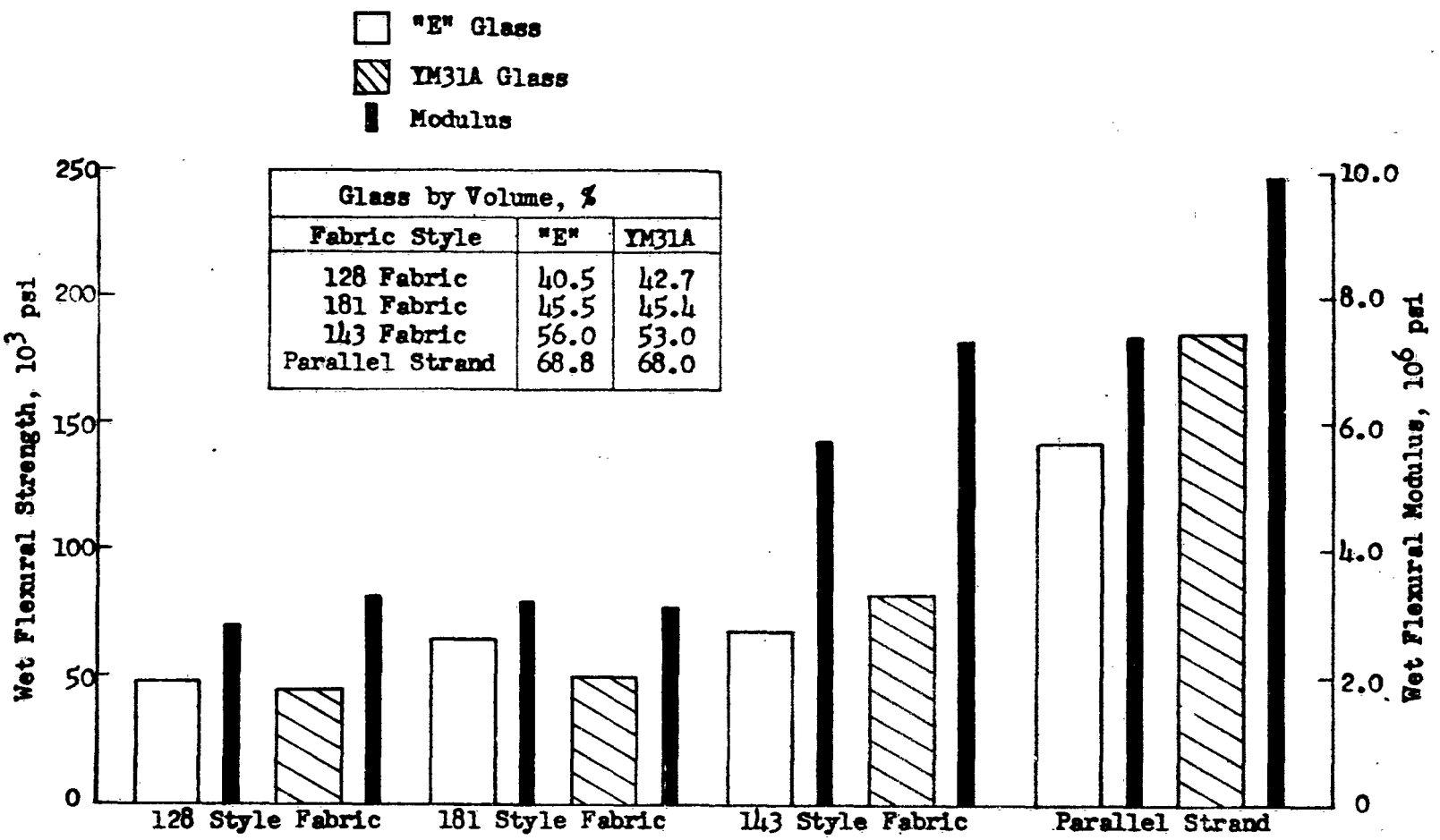


Figure 6 - Effect of Reinforcement Structure on Wet Flexural Properties of "E" and YM31A Glass Laminates

Resin: Paraplex P-43 **Finishes: Volan A for Fabric - 08 Treatment for Strand**

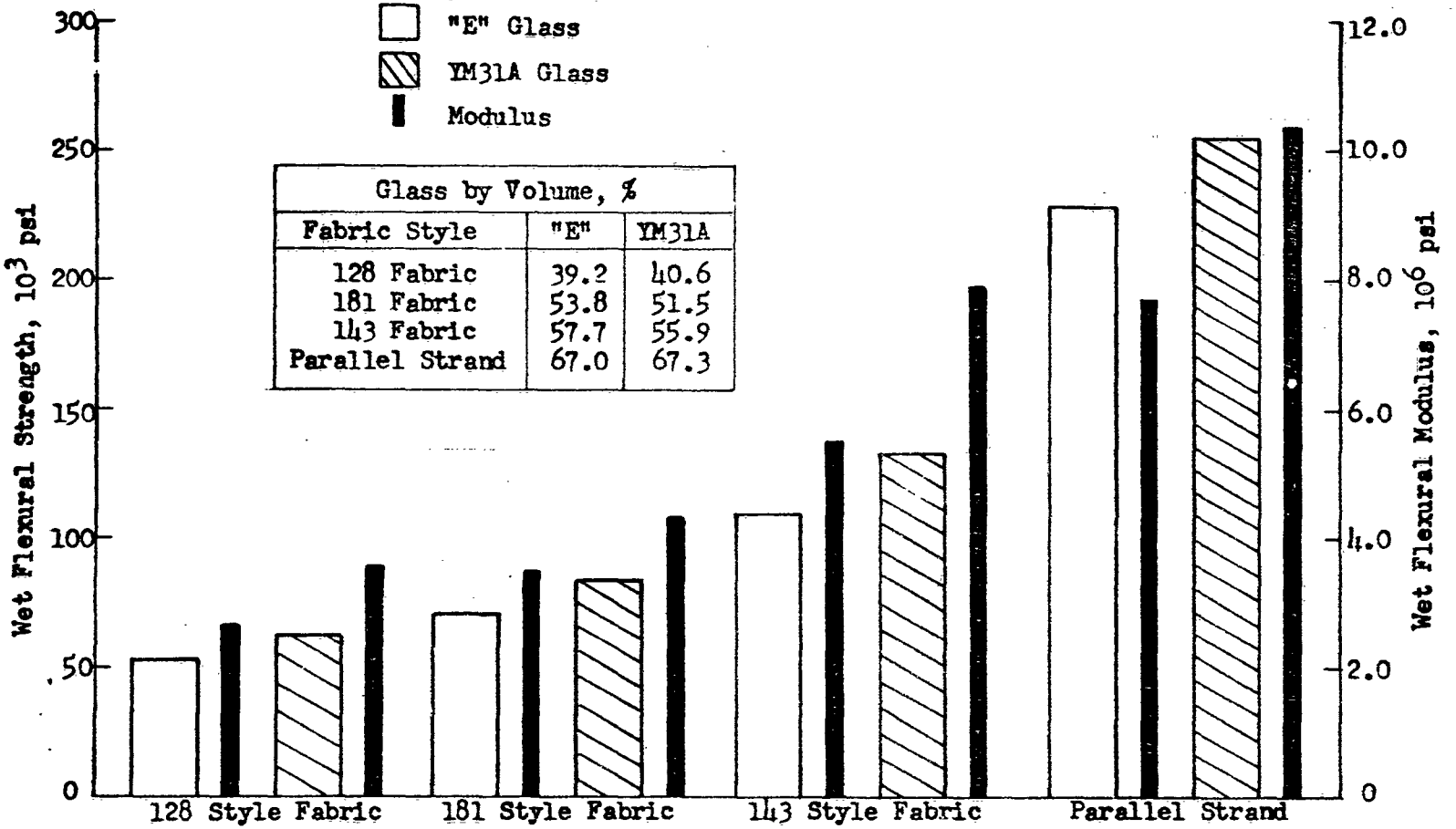
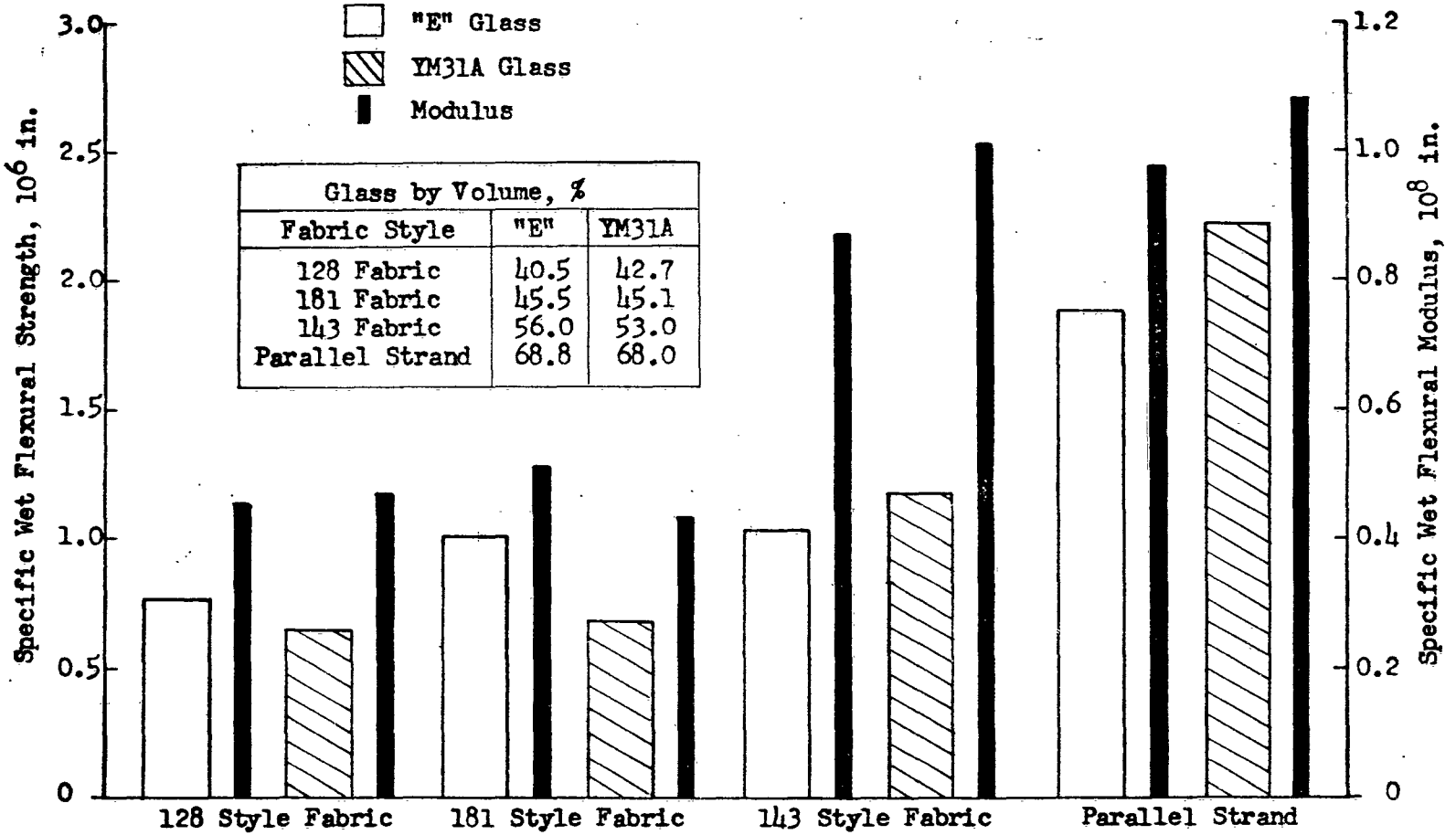


Figure 7 - Effect of Reinforcement Structure on Wet Flexural Properties of "E" and YM31A Glass Laminates

Resin: Epon 828/CL Finish: A-1100



Glass by Volume, %		
Fabric Style	"E"	YM31A
128 Fabric	40.5	42.7
181 Fabric	45.5	45.1
143 Fabric	56.0	53.0
Parallel Strand	68.8	68.0

Figure 8 - Effect of Reinforcement Structure on Specific Wet Flexural Properties of "E" and YM31A Glass Laminates

Resin: Paraplex P-43 Finishes: Volan A for Fabric - 08 Treatment for Strand

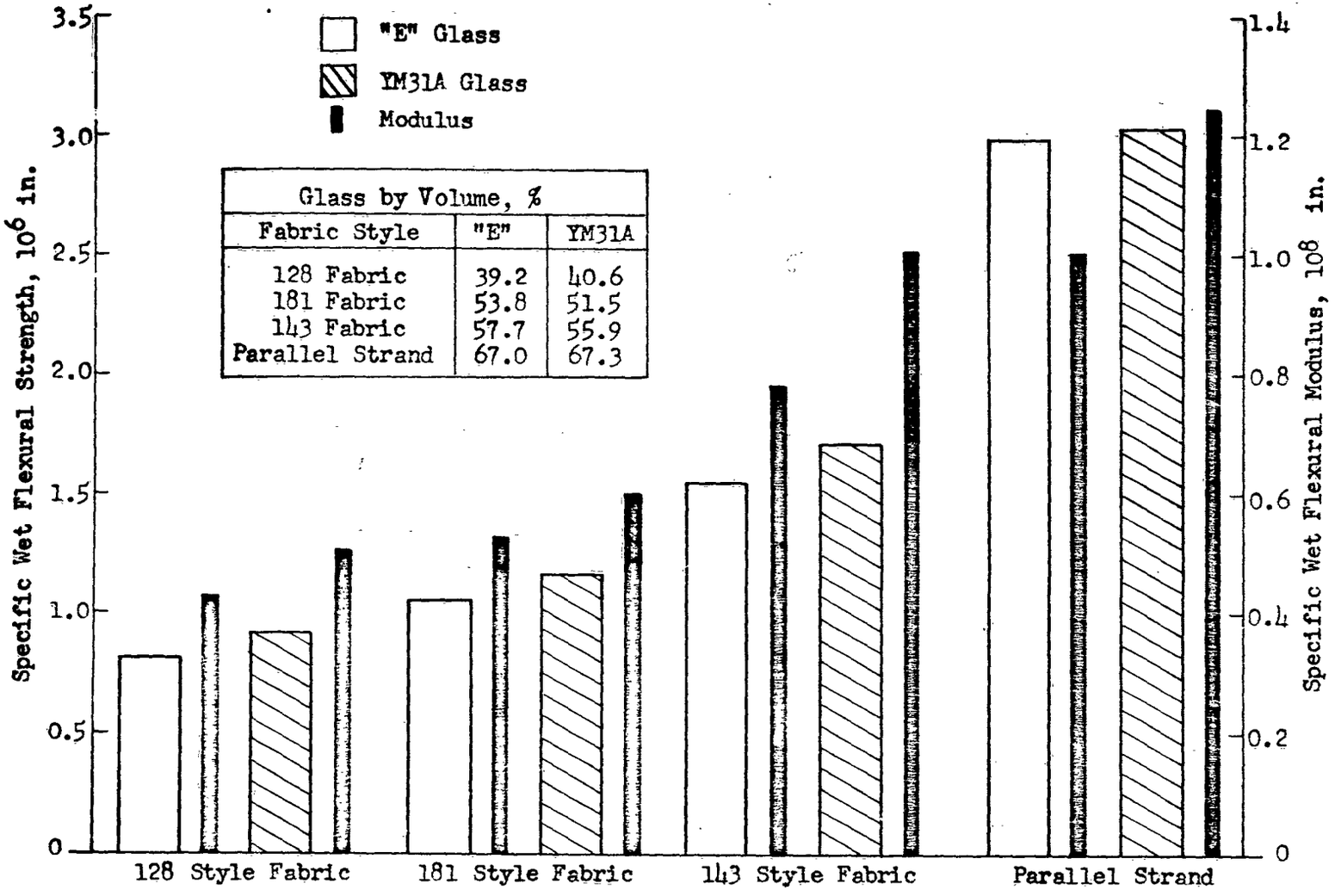


Figure 9 - Effect of Reinforcement Structure on Specific Wet Flexural Properties of "E" and YM31A Glass Laminates

Resin: Epon 828/CL

Finish: A-1100

reinforced plastics even when a tightly woven material is used as the reinforcement. The lower resin modulus allows more stress distribution during test.

When expressing the wet flexural strength and modulus as a "specific" value to include the weight of the laminated specimen, YM31A glass still appears to be a superior reinforcement than "E" glass (Figures 8 and 9). Of course, this superiority depends on the type resin used and the reinforcement structure. Using Epon 828 epoxy resin and A-1100 finish, YM31A glass laminates were found to be superior to "E" glass for every property with the exception of wet compressive strength values regardless of the reinforcement structure used. Specific strengths were calculated by dividing the laminate strength or modulus expressed in pounds per square inch by the weight in pounds per cubic inch.

Radius of Curvature in Bending

Use of YM31A glass as a reinforcement results in higher flexural strengths of reinforced plastics over that obtained with "E" glass. One possible reason for the higher strength values can be related to the higher modulus of YM31A glass.

The deflection which takes place when a bar is loaded in flexure can be related to the strength levels obtained. YM31A glass as a reinforcement increases the flexural modulus of the test specimen over that obtained with "E" glass. YM31A glass reinforced plastics should, therefore, undergo less deflection during test. By viewing a reinforced plastic specimen under a flexural test as a beam in bending, the following relationship should hold:

Calculation for Radius of Curvature

$$\rho = \frac{EI}{Mb}$$

where ρ = radius of curvature
E = Modulus of Elasticity in Flexure
I = Moment of Inertia
Mb = Bending Moment

The term "radius of curvature" can best be explained by viewing Figure 10. Since this measurement was convenient and readily obtained, it was used to express the deflection of a beam in bending. Longer radii of curvature indicate small deflections while shorter radii indicate large deflections with an applied load.

The modulus of the material and bending moment both affect the radius of curvature. YM31A glass reinforced plastic materials require more applied load to produce a deflection equal to that obtained with "E" glass.

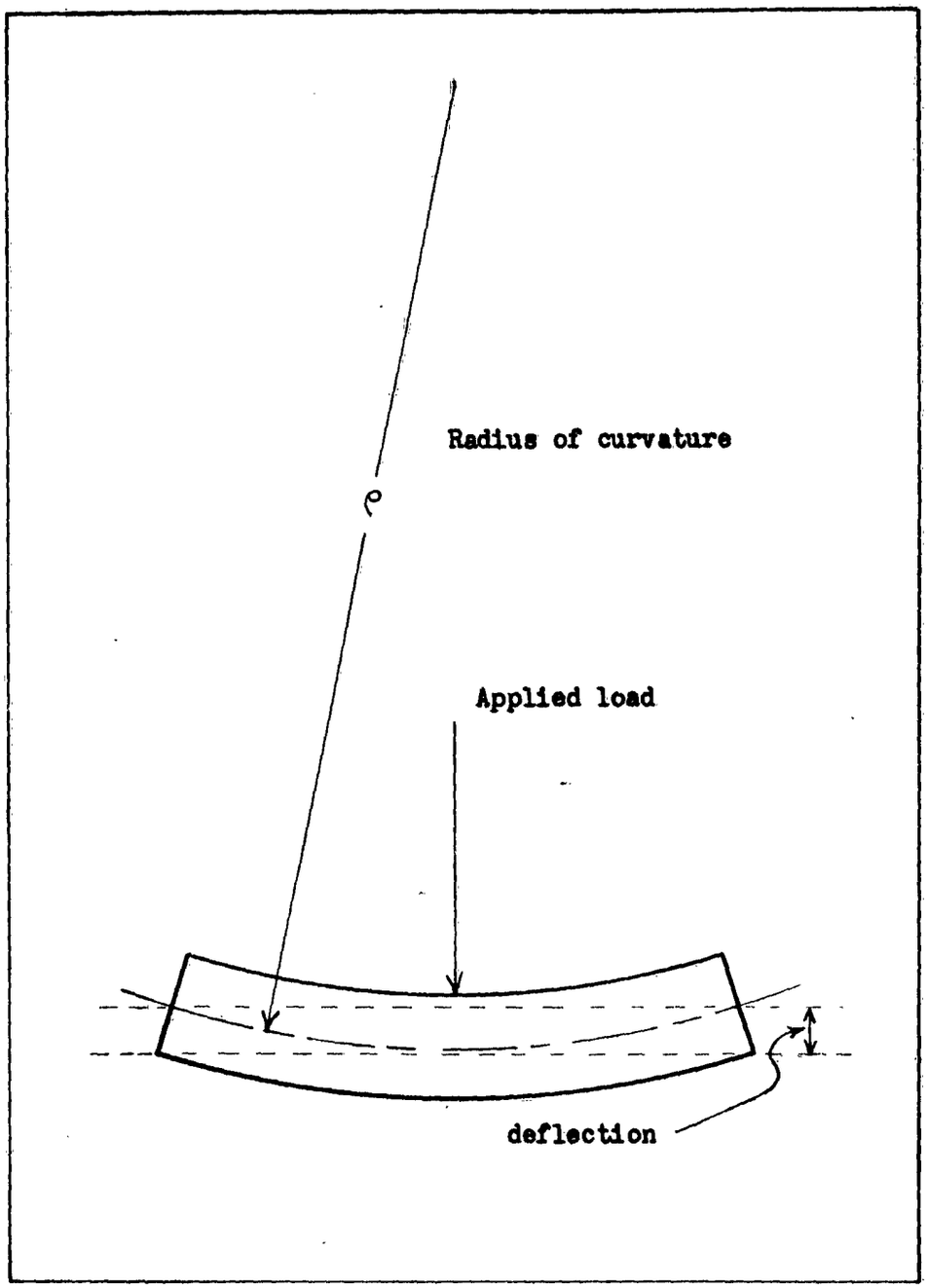


Figure 10 - Radius of Curvature and Deflection of a Beam in Bending

Radii of curvature were measured at failure for each sample. In order to study the deflection of the specimens at lower stress levels, additional radii values were calculated by the substitution of lower applied loads in the equation. The modulus value for the particular bar molding was kept constant for each calculation.

Radii of curvature were calculated for bar moldings described in Table XXXIII. The values obtained are presented in Figure 11 for Epon 828 bars, which were reinforced with parallel strands and in Figure 12 for Paraplex P-43 bars, which were reinforced with tape.

Discussion of Results

Epon 828. The data presented show that YM31A glass reinforced bars, those having a higher modulus, deflect to a lesser degree than bars reinforced with "E" glass. Both "E" and YM31A glass specimens failed at nearly equal radii of curvature 2.3 and 2.5 inches, respectively. More load was required, however, in bending the YM31A glass reinforced molding to nearly the same deflection as the bars reinforced with "E" glass.

Paraplex P-43. Radii of curvature calculated for bar moldings reinforced with "E" or YM31A glass tape show a similar relationship to those obtained with parallel strand reinforced bars. The premature failure tends to indicate a glass rather than resin failure which substantiates the conclusion drawn for reinforcement structure. Weave constrainment plays an important part in the behavior of YM31A glass in Paraplex P-43 resin.

Shear Stress Values in Bending

The reinforced plastic may fail through shear stresses built up within the specimen during test. Since the function of the resin is to hold the reinforcement together and transfer applied stresses to the glass, failure of the specimen can be traced to the shear stress bearing capacity of the resin. The degree to which shear stresses are present can be estimated by the following relationship:

$$S_s = \frac{3}{2}\frac{V}{A}$$

where S_s = Maximum shear stress
V = Vertical shear force
A = Cross-sectional area

Values for maximum shear stress were calculated for "E" and YM31A glass reinforced bar moldings and are presented in Table XXXIV.

Discussion of Results. The results obtained indicate that YM31A glass parallel strand reinforcement enables the composite to support

TABLE XXXIII

PROPERTIES OF BAR MOLDINGS WHICH WERE USED IN RADIUS OF CURVATURE CALCULATIONS

Tape Reinforcement	Wet Flexural Strength 10^3 psi after two hour boil	Wet Flexural Modulus 10^6 psi after two hour boil	Load Applied To Rupture (lbs)	Thickness (in)	Width (in)	Length (in)	Glass by Vol. (%)
RESIN: EPON 828 FINISH: A-1100							
"E" Glass Parallel Strand	225.8	7.62	851	0.124	0.752	2.0	67.0
YM31A Glass Parallel Strand	252.5	10.26	956	0.123	0.752	2.0	67.3
RESIN: PARAPLEX P-43 FINISH: Volan A							
"E" Glass Tape	47.7	2.87	157.5	0.115	0.750	2.0	40.5
YM31A Glass Tape	45.9	3.24	155.5	0.116	0.751	2.0	42.7

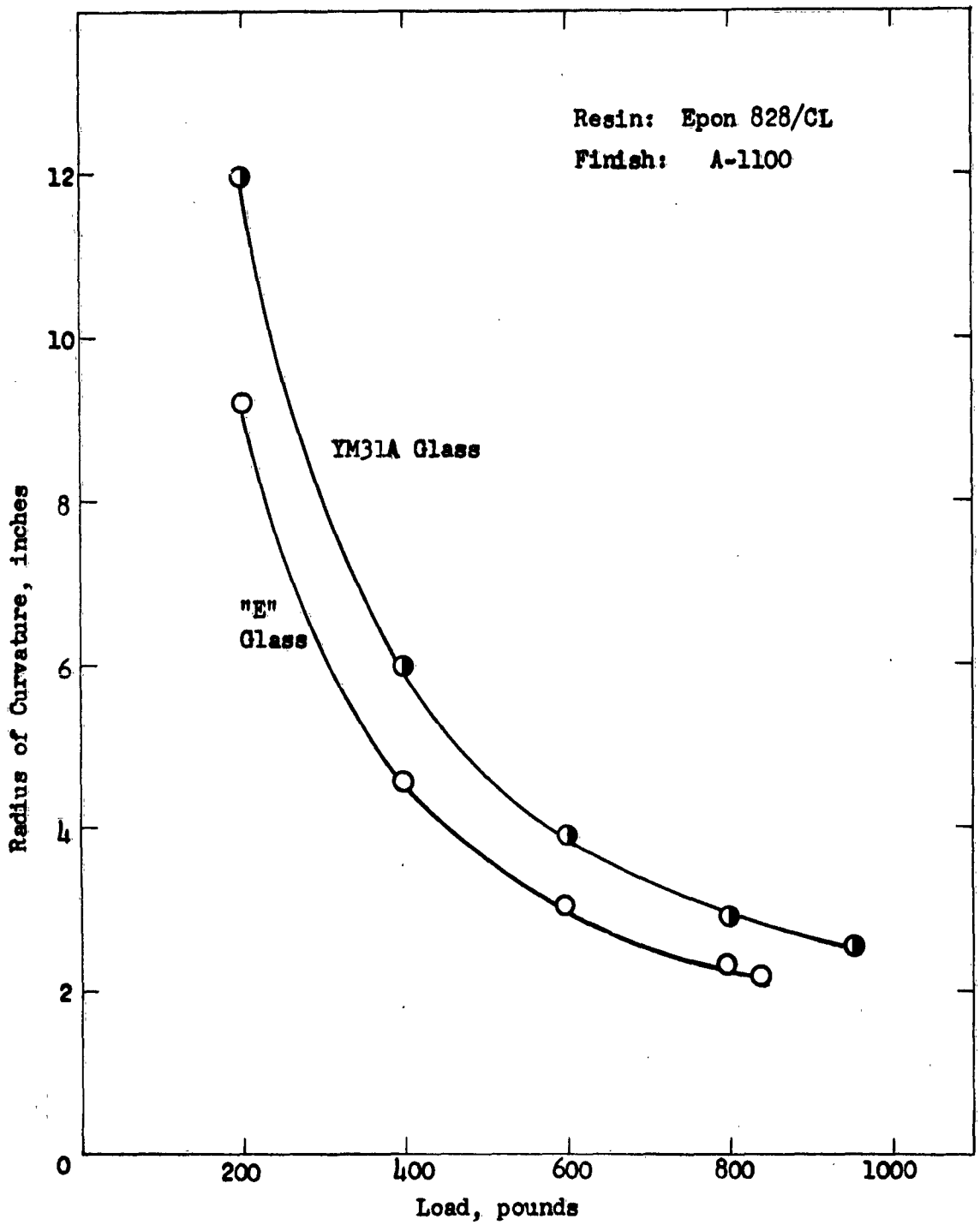


Figure 11 - The Relationship Between Load Applied to Specimen during Test and Radius of Curvature for Parallel Strand Reinforced Bar Moldings

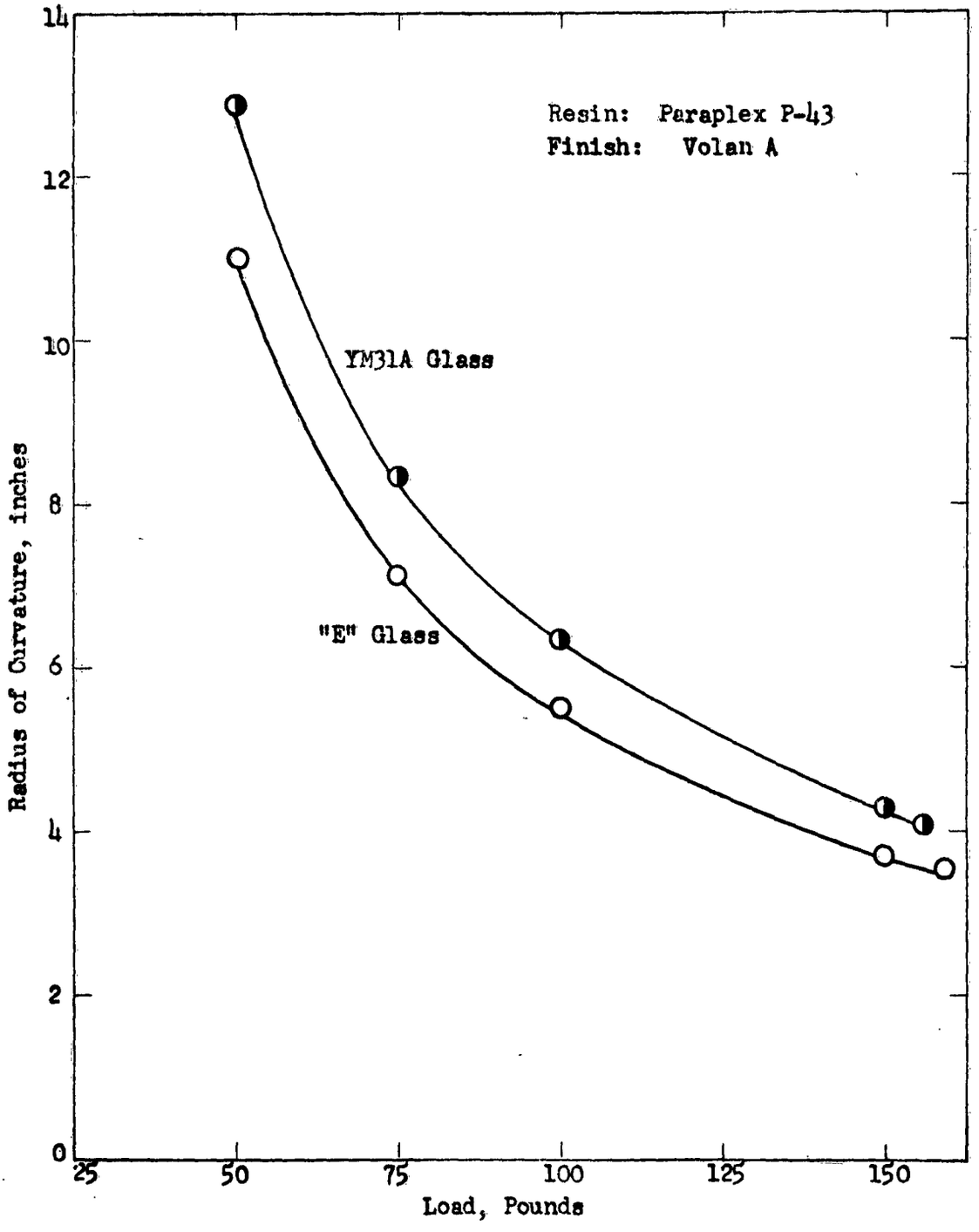


Figure 12 - The Relationship Between Load Applied to the Specimen during Test and the Radius of Curvature for Glass Tape Reinforced Bar Moldings

TABLE XXXIV

MAXIMUM SHEAR STRESS AT RUPTURE FOR "E" AND YM31A GLASS REINFORCED BARS

	Load Applied During Test	Specimen Thickness (in.)	Specimen width (in.)	Max. Shear Stress at Rupture x 10^3 psi
Epon 828 reinforced with:				
"E" Glass-parallel strand	851	0.124	0.752	6.86
YM31A Glass-parallel strand	956	0.123	0.752	7.71
Paraplex P-43 reinforced with:				
"E" Glass tape (plain weave)	157.5	0.115	0.750	1.37
YM31A Glass tape (plain weave)	155.5	0.116	0.750	1.34

more shear stress before failures. Tape reinforced bars at lower glass loadings have nearly equal shear stresses present.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions drawn from the data have been presented in the order of their appearance in the text. They are as follows:

Yarn Construction Variations

1. A comparison of 181 style fabric woven from "E" glass in 51 and 204 filament strands imbedded in Paraplex P-43 resin indicates no significant differences in laminate flexural strengths. Based upon these results and other experimental work, no significant advantage is seen in using 204 filament YM31A glass strand versus the available 51 filament strand plied four times. Conversely, no significant damage should be incurred in using the four ply 51 filament strand. Development of a bushing to form 204 filament YM31A glass strand is not recommended for current research and development work.

Heat Cleaning and Desizing Variations

1. Standard heat cleaned material as a reinforcement can be used with no deleterious effects on laminate flexural strengths for both "E" or YM31A glass. No combination of solvents, enzymes and chemicals was found which could remove all of the 630 size without a short-time heat treatment. No chemical method of size removal followed by short-time heat treating was found to be better than standard heat cleaning glass reinforcements for plastics. Since the chemical methods studied required short heat treatments, this system seems uneconomical. The chemical methods used offer no advantage strengthwise, hence, standard heat cleaned materials should be used.

Resin-Finish-Systems

1. Laminates made with Epon 828 epoxy resin or CTL 91-LD phenolic resin reinforced with A-1100 finished YM31A glass tape had higher flexural properties than similar "E" glass moldings. The investigation should be extended to other epoxy and phenolic resin-finish-systems to develop similar information.

2. For YM31A glass and polyester resins, Volan A gives higher flexural strengths than Garan finish using polyester resins only. Parallel strand and 143 style fabric are comparable with "E" glass.

Reinforcement Structure

1. Reinforcement structure always affects the strengths of plastic laminates. The structure of the reinforcement can either increase or lower the flexural strengths of YM31A glass laminates above or below strengths of similar "E" glass moldings. With Epon 828 and A-1100 finish, moldings reinforced with YM31A 128, and 143 style fabrics and parallel strand reinforcements showed higher strengths than similar "E" glass moldings. With Paraplex P-43 and Volan A finished material, YM31A parallel strand and 143 style fabric reinforcement were stronger than similar "E" glass moldings; but YM31A 128 and 181 style fabric reinforcements gave lower strengths than similar "E" glass moldings. It is believed that yarn constraint, caused by weave construction, reduces the effectiveness of YM31A glass as a reinforcement for polyester resins. The best resin-finish combinations for YM31A glass found during this work which gave laminate strengths greater than similar "E" glass moldings are as follows and are recommended for use:

a. Epoxy Resin System

Resin:	Epon 828
Hardener:	14 pph meta-phenylene diamine
Finish:	A-1100
Reinforcement:	128 style tape, 181 style fabric, 143 style fabric, or parallel strand.
Primary Cure:	one hour at 250°F
Post Cure:	one hour at 375°F
Pressure:	Moldings were made using both contact pressure and molding pressure with no adverse effects to YM31A glass. Additional work should include an investigation of pressure moldings on YM31A glass.

b. Phenolic Resin System

Resin:	CTL 91-LD*
Reinforcement:	128 style tape
Finish:	A-1100
Primary Cure:	20 minutes at 300°F
Post Cure:	24 hours at 300°F 24 hours at 350°F 24 hours at 400°F

c. Polyester Resin System

Resin:	90 pbw Paraplex AP-174 or Paraplex P-43 and 10 pbw Styrene
Catalyst:	1 pbw Benzoyl peroxide crystals.
Reinforcement:	For Paraplex P-43 1. 143 style fabric 2. Parallel Strand For Paraplex AP-174* 1. Parallel Strand
Finish:	Volan A or 08 Treatment
Cure:	15 minutes at 230°F

*Additional work should be done to extend information to include other reinforcement structures.

PHASE III

HIGH MODULUS HIGH STRENGTH PLASTIC LAMINATES USING NONWOVEN FIBER REINFORCEMENTS

Objective: The parallel strand bar molding technique was used to optimize resin-glass systems with unidirectional reinforcements. The object was the development of nonwoven preimpregnated reinforcement suitable for practical molding.

INTRODUCTION

Experience in working with reinforced plastics has proved that parallel wound structures can give better mechanical properties than any other form of glass reinforcements. The ability to place the glass where it is needed and to orient it in the directions of greatest stress have been largely responsible for these better properties.

The purpose of this study was the development of a nonwoven preimpregnated reinforcement suitable for practical molding. This reinforcement consisted of parallel strands having even tension and a finish compatible with the resin selected. The target properties for this product when evaluated in a molded part were:

1. "E" glass with room temperature resin

Flexural strength, dry	210,000 psi
Flexural strength, wet	185,000 psi
Flexural modulus, dry	7.0×10^6 psi

2. "E" glass with heat-resistant resin

Flexural strength, dry	180,000 psi
Flexural strength, wet	145,000 psi
Flexural strength at 500°F after 192 hours at 500°F	80,000 psi
Flexural modulus, dry	6.0×10^6 psi

3. YM31A glass with room temperature resin

Flexural strength, dry	210,000 psi
Flexural strength, wet	185,000 psi
Flexural modulus, dry	10.5×10^6 psi

SUMMARY

Initial Screening Study

Fifteen resin-finish-glass systems were studied with "E" glass to determine which one should be selected for optimization in a nonwoven plastic laminate. With both roving and yarn, Paraplex AP-174 high strength polyester gave the best dry flexural strengths and, hence, was chosen as the resin for further work.

The flexural strength of the parallel strand bars increased almost linearly with glass content to a maximum point for every resin-finish-glass system. This maximum was reached when either:

1. The glass content was so high that there was a breakdown of the glass-to-resin bond during the test as a result of incomplete wetting of the fibers; or
2. The glass content was so high that the shear strength of the bar was drastically reduced, which caused the specimen to be damaged during the removal from the mold. This also is believed to be a result of incomplete wetting of the fibers.

Paraplex AP-174 Resin with "E" Glass

This resin system was very stable to variations in cure. Over the ranges studied none of the cure variables affected the flexural properties of the molded parallel strand bars.

The flexural properties were affected only by certain material variables and by variations in the glass content.

The best values obtained are shown in Table XXXV.

Vibrin 136A Resin With "E" Glass

Parallel strand moldings with Garan finished yarn showed dry and wet flexural properties which exceeded the target properties of this program. Flexural properties tested at 500°F after 1/2 hour at 500°F, however, were lower than the target properties. Data are presented in Table XLIX.

Paraplex AP-174 Resin With YM31A Glass

A translation of the process for molding parallel strand specimens from "E" glass to YM31A glass gave excellent results when the reinforcement was 08 treated yarn. A silane sized roving (830 size) gave much poorer results. The best results are shown in Table XXXVI.

TABLE XXXV

SUMMARY OF MAXIMUM FLEXURAL PROPERTIES OF PARALLEL STRAND BARS AFTER ANALYSIS OF BALANCED EXPERIMENT

RESIN: Paraplex AP-174
REINFORCEMENT: "E" Glass

	Flexural Properties			
	Strength, 10^3 psi		Modulus, 10^6 psi	
Reinforcement Construction	Dry	2 hour boil	Dry	2 hour boil
880 sized roving	265	247	7.81	7.78
Garan Finished Yarn	247	-	8.01	-

TABLE XXXVI

PROPERTIES OF PARALLEL STRAND BARS

RESIN: Paraplex AP-174
REINFORCEMENT: YM31A Glass
08 Treated Yarn

Flexural Properties			
Strength, 10^3 psi		Modulus, 10^6 psi	
Dry	2 hour boil	Dry	2 hour boil
268	210	10.5	10.7

Winding and Packaging the Preimpregnated Product

Paraplex AP-174 resin and 880 sized roving were combined into a one half inch wide preimpregnated tape and wound onto a spool. This material was moldable for a period of one month when stored at room temperature.

DISCUSSION

Initial Screening Study

The first portion of this development was a screening study on candidate resin-finish-"E" glass systems. Fibrous glass reinforcements both in the form of rovings and heat cleaned and finished yarns were included in this screening work. Parallel strand molded bars were molded and tested for flexural and compressive strengths and flexural modulus. One single resin was chosen, but various finishes were used with it for optimization. This information was later translated to a heat resistant resin with "E" glass and to a resin-finish combination with YM31A glass from Phase II.

The hundreds of possible resin finish combinations made it necessary to eliminate most of them from actual experimentation. Selection of the resins and reinforcements which were used was based on previous experience in molding and on recent developments in the resin industry.

Resins. Seven resins were chosen for experimental work. Previous experience on Contract AF 33(600)-35031 work showed that flexural strengths in the vicinity of 200,000 psi could be obtained with conventional polyesters in parallel strand reinforced specimens. Also, since initial work was concerned only with room temperature properties, the heat resistant resins were eliminated. Finally, recent developments in the chemical industry have resulted in several new resins which were worth investigating.

Several of the resins chosen for this work are still developmental and have not been qualified under the military specifications. However, this does not preclude their ability to meet the specifications. They were included in this study because of their individual possibilities, not because of established conformity.

The resins selected were:

1. Paraplex P-43 produced by Rohm & Haas. This is a conventional polyester resin using styrene as the cross-linking agent. Its widespread use made it ideal for consideration as the final choice as well as a basis for comparison with other resins.

2. Paraplex AP-174 produced by Rohm & Haas. This is a high strength polyester resin not yet in full production. Its superior properties demonstrated by Rohm & Haas and ease of handling made it ideal as a candidate for the high strength laminate study.

3. Epon 828 produced by Shell Chemical Corporation. This is a conventional epoxy resin exhibiting good strength properties and some heat resistance. Its properties in a molded part are well suited for comparison on a strength basis with other materials.

4. Plaskon 911 produced by the Coal Chemicals and Plastics Division of Allied Chemical Corporation. This conventional polyester uses diallyl phthalate as the cross-linking agent and can be used to impregnate glass fibers from a solvent system.

5. Isolite 761A produced by Schenectady Paint and Varnish Company. This polyester resin is one of a class of polyesters which utilized isophthalic acid in the manufacturing process. Much publicity has been given to these resins lately which in many applications have shown improved properties.

6. Atlac 382X with 10 per cent methacrylic acid produced by the Bisphenol A, one of the constituents of epoxy resins, is used in the manufacture of this polyester resin. The addition of 10 per cent methacrylic acid is claimed to result in very high strengths in a molded part.

7. Buton resin produced by Esso. This is an all hydrocarbon resin and is a liquid copolymer of butadiene and styrene in the approximate weight ratio of 80/20. It has exhibited good strength properties as well as an ability to be partially cured to a nontacky preimpregnated product.

Reinforcements

Yarn - Yarns with various finishes were used as one form of reinforcement. The particular finishes employed were compatible with the resins used. In all cases, the reinforcement was 8 ends of 150's 1/0 yarn which were wound together before heat cleaning and finishing.

Roving - The other form of reinforcement studied was fiber roving. The individual strands had a size applied when they were formed which was compatible with certain resins. Hence, there was no need for heat cleaning or finishing. All roving was formed from 138's strands. The following binders or sizes were used:

1. 880 size. This is a silane size which is compatible with polyester resins.

2. 801 size. This is a size compatible with epoxy and phenolic resins.

3. Buton size. This is a developmental size produced only for use with Buton resin. The size is applied from an emulsion of the resin itself.

Preparation of Specimens

All the materials were molded using the bar molding process. A complete description of this process was given in the final report on AF33 (616)-5802 Supplement I. (WADD TR 60-24).

Each of the seven resins was used with two forms of reinforcements. These combinations, along with the exact amount of catalyst, solvent, and the curing conditions are outlined in Table XXXVII.

Because of the lack of adequate space in Table XXXVII, no explanation was given of the composition of Atlac 382-X and Buton resins. Atlac 382-X contained 10 per cent of methacrylic acid already mixed in it. Buton was mixed as follows:

60 parts Buton resin
40 parts vinyl toluene
2 parts 55 per cent divinyl benzene
2 parts dicumene peroxide
2 parts di-t-butyl peroxide
0.5 parts benzoyl peroxide

Six to ten parallel strand bars were molded with different glass contents for each resin-reinforcement system. The glass volume was varied from about 55 per cent to about 70 per cent for each system. Bars were molded initially using the amount of glass expected to give about 50 per cent glass content. Then, the glass content was increased progressively until it was impossible to remove the bars from the mold undamaged.

For AP-174 and Atlac 382-X resins, the mold surfaces were sprayed with polyvinyl alcohol instead of Garan mold release as was done with the other resins. Both Atlac 382-X with methacrylic acid and Paraplex AP-174 have high acid numbers. The Garan mold release could not prevent some cure inhibition at the mold surface.

All bars were tested according to the specifications in LP406b. Flexural and compressive properties were measured as well as specific gravity, ignition loss and glass content by volume.

TABLE XXXVII

PREPARATION OF PARALLEL MOLDED BARS

Resin	Reinforcement	Catalyst or Hardener	Cure Time	Cure Temp.
Epon 828	08 treated yarn	14 pph of m-phenylene diamine	One hour	235°F
Epon 828	801 sized roving	14 pph of m-phenylene diamine	One hour	235°F
P-43, 90 ppw Styrene, 10 ppw	08 treated yarn	1% Benzoyl peroxide	15 minutes	225°F
P-43, 90 ppw Styrene, 10 ppw	Garan finished yarn	1% Benzoyl Peroxide	15 minutes	225°F
P-43, 90 ppw Styrene, 10 ppw	880 sized roving	1% Benzoyl Peroxide	15 minutes	225°F
AP-174, 90 ppw Styrene, 10 ppw	Garan finished yarn	1% Benzoyl Peroxide	30 minutes	250°F
AP-174, 90 ppw Styrene, 10 ppw	880 sized roving	1% Benzoyl Peroxide	30 minutes	250°F
Atlac* 382-X	Garan finished yarn	2% Benzoyl Peroxide	30 minutes	250°F
Atlac* 382-X	880 sized roving	2% Benzoyl Peroxide	30 minutes	250°F
Plaskon 911	Garan finished yarn	2% Benzoyl Peroxide	30 minutes	250°F
Plaskon 911	880 sized roving	2% Benzoyl Peroxide	30 minutes	250°F
Isolite 761-A	Garan finished yarn	1% Benzoyl Peroxide	15 minutes	225°F
Isolite 761-A	880 sized roving	1% Benzoyl Peroxide	15 minutes	225°F
C-oil*	C-oil roving		One hour	300°F
C-oil*	A-172 finished yarn		One hour	300°F

*A description of the exact composition is found in the text.

Discussion of Results

General - The test data for all bars are tabulated in the Appendix, Tables LXI through LXVIII. Graphs are presented for the per cent glass by volume versus the flexural and compressive strengths. Graphs are also presented to show the effect of glass content on the flexural moduli of the different resin-glass combinations. These tables and graphs show that the strengths and moduli are a function of the glass content.

Flexural Strengths. - The flexural strengths, in general, increased linearly with increasing glass content until a maximum point was reached. Then they decreased rapidly. This maximum point was reached when:

1. The glass content was so high that there was a breakdown of the glass-to-resin bond, due to incomplete wetting and bonding of the fibers.

2. The glass content was so high that there was relatively little resin shrinkage during cure and the specimen was damaged in removal of the mold.

Table XXXVIII shows the maximum flexural strength obtained for each resin-reinforcement system. Also shown is the glass content and the flexural modulus for these maximum strength bars. The variation of the glass content which gave the maximum strength is due to two factors:

1. The variation in the efficiency of the resin-finish-glass bond. The different resins and finishes used each have stress limits after which the structure collapses.

2. Non-uniformity in the orientation of the glass fibers. Ideally, all the strands of glass in the bars are parallel to each other and oriented in the direction of greatest stress. Due to slight variations in the winding technique and strand tension, however, some of the strands are slightly crossed. This can create stress concentrations within the bar due to eccentric loading and cause a breakdown of the structure.

The two resin-glass combinations which gave the maximum flexural strength were Paraplex AP-174 with 880 sized roving and the same resins with Garan-finished yarn. This resin has been chosen for the development of a preimpregnated parallel strand reinforcement in this program. Its superior properties are mainly responsible for this decision, but it can also be handled with the ease of a low viscosity conventional polyester resin.

With Epon 828 resin and 801 sized roving, four bars of different glass contents were boiled in distilled water for two hours. This was

TABLE XXXVIII

INITIAL SCREENING STUDY
PROPERTIES OF PARALLEL STRAND BARS HAVING HIGHEST FLEXURAL STRENGTH

Resin	Type Reinforcement	Maximum Flexural Strength 10^3 psi	Specific* Value 10^6 in	Flexural Modulus 10^6 in	Specific* Value 10^6 in	Glass Volume %
Paraplex AP-174	880 sized roving	276	3.59	8.02	1.04	71.4
Paraplex AP-174	Garan finished yarn	247	3.26	7.53	0.99	67.3
Epon 828	08 treated yarn	236	2.94	8.87	1.11	77.0
Atlac 382-X	Garan finished yarn	227	2.95	7.88	1.02	70.0
Paraplex P-43	Garan finished yarn	223	3.00	7.50	1.01	65.4
Epon 828	801 sized roving	222	2.96	7.79	1.04	69.3
Paraplex P-43	880 sized roving	221	3.03	7.54	1.03	65.2
Paraplex P-43	08 treated yarn	215	2.81	7.50	0.98	66.4
Isolite 761-A	880 sized roving	196	2.81	7.70	1.10	67.5
Atlac 382-X	880 sized roving	193	2.51	7.17	0.94	70.0
Plaskon 911	Garan finished yarn	187	2.52	7.66	1.03	64.6
Plaskon 911	880 sized roving	163	2.08	7.71	0.98	71.9
Buton	A-172 finished yarn	145	2.03	6.77	0.95	64.2
Isolite 761-A	Garan finished yarn	143	1.96	7.41	1.02	64.5
Buton	Buton sized roving	118	1.69	7.62	1.08	66.4

*Specific Value = $\dfrac{\text{Actual Value}}{\text{Specific Gravity} \times \frac{62.4}{1728}}$ Units are psi/lbs/in^3

the only combination of resin and finish tested for wet properties. Up to a glass content of about 63 per cent by volume, the wet and dry flexural strengths stayed about equal. From 63 per cent to about 70 per cent glass content, the dry flexural strength increased at a faster rate than the wet flexural strength. An explanation of this phenomenon is that at higher glass contents the wetting out of the glass by the resin was not complete. Water could then more easily enter the structure and weaken the bars.

Flexural Modulus. The flexural modulus generally increased proportionally to the flexural strengths but in most cases it kept increasing beyond the maximum point for flexural strengths. This can be explained by the fact that the modulus value is calculated from the initial portion of the stress-strain curve. Although in many cases there was not enough resin to hold the specimen together for high ultimate strength, the initial slope continued to increase as the glass content was raised.

Compressive Strength. The compressive strengths, in general, increased with increasing glass content but at a much lower rate than the flexural strengths. The maximum point for each resin-glass reinforcement combination was always at a lower glass content than that for maximum flexural strengths. For many of the glass-resin combinations the data showed that the glass content for maximum compressive strength is outside the experimental region. Since this program was directed toward flexural properties rather than compressive properties, no attempt was made to find the optimum glass content for compressive strength.

When the bars were tested for compressive strength, failure always occurred at the top of the specimen. This is the portion of the specimen which extends beyond the supporting jig. The fibers blossomed in a mushroom shape at the point of maximum load.

Paraplex AP-174 Resin With "E" Glass - First Experiment

As a result of the screening study, Paraplex AP-174 resin was chosen for further evaluation. The parallel strand bars for the screening study were molded under conditions recommended by Rohm & Haas Company. Since there are many material and process variables which can effect the properties of a reinforced plastic, a systematic investigation of these variables was carried out.

A forty-run balanced experiment[1] investigated the importance of material and process variables involved in molding parallel strand reinforcements with AP-174 resin. Sixteen variables, each at two levels, were involved in this experiment. The sixteen different variables and their levels are shown in Table XXXIX. The molding conditions for all forty parallel strand moldings are shown in Table XL.

Further explanation of some of the variables in Table XXXIX is necessary for complete interpretation of the experiment.

Resin Mixture

Paraplex AP-174, produced by Rohm & Haas, is a standard polyester resin formulated for high strength. It is not yet in full production. Styrene is used with this resin as a reactive diluent. Benzoyl peroxide is commonly used as a catalyst. Variations in the amounts of both styrene and benzoyl peroxide were studied in order to discover their effects on the specimen properties.

Reinforcements

The type of yarn used was eight ends of 150's 1/0 glass fibers which were wound together before heat cleaning. The yarn was finished with Garan finish after a standard heat cleaning cycle.

The other form of reinforcement was 880 sized roving. For this reinforcement the individual strands had the size applied when they were formed. Tubes with eight ends of 130's strands were used as a supply for winding the bars.

Variables in Mold Preparation

Another variable under the control of the molder is the way of preparing the mold. The degree of crossing of the strands in winding can be reduced by using a reed. Eight packages of Garan finished yarn or 880 sized roving were wound at the same time by passing the strands through a reed. The strands were kept absolutely parallel as they were wound on the mold.

For the second level of this variable, three packages were wound together by passing all three 8-end strands through a guide eye. The guide eye was directed to wind the strand on the mold as parallel as

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[1]Owen L. Davies. Design and Analysis of Industrial Experiments, 2nd Edition, 1956, (New York: Hafner Publishing Co.), Chapter 10, pp 440-494.

TABLE XXXIX

MATERIAL AND PROCESS VARIABLES STUDIED WITH PARAPLEX AP-174
RESIN AND "E" GLASS REINFORCEMENTS
EXPERIMENTAL DESIGN 2^{16-11}

	Variables	Levels 1 vs 2	
1	Styrene Addition, %	10	0
2	Benzoyl Peroxide Catalyst Concentration, %	2	1
3	Degas Resin, Minutes	30	0
4	Reinforcement, Garan Finished Yarn or 880 Roving	880	Garan
5	Number of 8-end packages wound at once	8	3
6	Width of Mold, inches	3/4"	1/2"
7	Prewarm Mold before Winding	15 min at 210°F	no prewarming
8	Speed of Winding, inches per minute	440	220
9	Turns of Mold (See text for details)	High	Low
10	Degas wound mold, minutes	30	0
11	Time of cure, minutes	30	15
12	Temperature of Cure, °F	250	225
13	Remove Hot of Cold After Cure	Hot	Cold
14	Postcure 30 minutes at 250°F	Yes	No
15	Specimen Preparation for Testing	Whole	Ends cut
16	Top or Bottom Concave in Flexu[illegible] Test	Top	Bottom

TABLE XI

PREPARATION OF PARALLEL STRAND SPECIMENS

EFFECT OF MATERIAL AND PROCESS VARIABLES WITH PARAPLEX AP-174 RESIN

Specimen Number	Styrene Addition, %	BPO Catalyst Concentration, %	Degas Resin, Minutes	Reinforcement Garan Finished Yarn or 880 Sized Roving	Number of 8-End Packages Wound at Once	Width of Mold, Inches	Preworm Mold Before Winding	Speed of Winding, Inches Per Minute	Turns on Mold	Degas Wound Mold, Minutes	Time of Cure, Minutes	Temperature of Cure, °F	Remove Hot or Cold After Cure	Postcure 30 Minutes at 250°F	Specimen Preparation for Testing	Top or Bottom Concave in Flexural Test
1	0	1	0	Garan	3	.5	No	220	[illegible]	0	15	225	Cold	No	Ends Cut	Bottom
2	10	1	0	Garan	3	.75	Yes	440	130	30	30	225	Cold	No	Ends Cut	Top
3	0	2	0	Garan	3	.75	Yes	440	115	0	15	250	Hot	Yes	Ends Cut	Top
4	10	2	0	Garan	3	.5	No	220	89	30	30	250	Hot	Yes	Ends Cut	Bottom
5	0	1	30	Garan	3	.75	No	220	130	30	15	250	Hot	No	Whole	Top
6	10	1	30	Garan	3	.5	Yes	440	77	0	30	250	Hot	No	Whole	Bottom
7	0	2	30	Garan	3	.5	Yes	440	89	30	15	225	Cold	Yes	Whole	Bottom
8	10	2	30	Garan	3	.75	No	220	115	0	30	225	Cold	Yes	Whole	Top
9	0	1	0	880	3	.5	Yes	220	89	[illegible]	30	250	Cold	Yes	Whole	Top
10	10	1	0	880	3	.75	No	440	115	30	15	250	Cold	Yes	Whole	Bottom
11	0	2	0	880	3	.75	No	440	130	0	30	225	Hot	No	Whole	Bottom
12	10	2	0	880	3	.5	Yes	220	77	30	15	225	Hot	No	Whole	Top
13	0	1	30	880	3	.75	Yes	220	115	30	30	225	Hot	Yes	Ends Cut	Bottom
14	10	1	30	880	3	.5	No	440	89	0	15	225	Hot	Yes	Ends Cut	Top
15	0	2	30	880	3	.5	No	220	77	30	30	250	Cold	No	Ends Cut	Top
16	10	2	30	880	3	.75	Yes	220	130	0	15	250	Cold	No	Ends Cut	Bottom

TABLE XL (Continued)

PREPARATION OF PARALLEL STRAND SPECIMENS

EFFECT OF MATERIAL AND PROCESS VARIABLES WITH PARAPLEX AP-174 RESIN

Specimen Number	Styrene Addition, %	BPO Catalyst Concentration, %	Degas Resin, Minutes	Reinforcement Garan Finished Yarn or 880 Sized Roving	Number of 8-End Packages Wound at Once	Width of Mold, Inches	Prewarm Mold Before Winding	Speed of Winding, Inches Per Minute	Turns on Mold	Degas Wound Mold, Minutes	Time of Cure, Minutes	Temperature of Cure, °F	Remove Hot or Cold After Cure	Postcure 30 Minutes at 250°F	Specimen Preparation for Testing	Top or Bottom Concave in Flexural Test
17	0	1	0	Garan	8	.5	No	440	29	30	30	225	Hot	Yes	Whole	Top
18	10	1	0	Garan	8	.75	Yes	220	49	0	15	225	Hot	Yes	Whole	Bottom
19	0	2	0	Garan	8	.75	Yes	220	43	30	30	250	Cold	No	Whole	Bottom
20	10	2	0	Garan	8	.5	No	440	33	0	15	250	Cold	No	Whole	Top
21	0	1	30	Garan	8	.75	No	440	49	0	30	250	Cold	Yes	Ends Cut	Bottom
22	10	1	30	Garan	8	.5	Yes	220	29	30	15	250	Cold	Yes	Ends Cut	Top
23	0	2	30	Garan	8	.5	Yes	220	33	0	30	225	Hot	No	Ends Cut	Top
24	10	2	30	Garan	8	.75	No	440	43	30	15	225	Hot	No	Ends Cut	Bottom
25	0	1	0	880	8	.5	Yes	440	33	30	15	250	Hot	No	Ends Cut	Bottom
26	10	1	0	880	8	.75	No	220	43	0	30	250	Hot	No	Ends Cut	Top
27	0	2	0	880	8	.75	No	220	49	30	15	225	Cold	Yes	Ends Cut	Top
28	10	2	0	880	8	.5	Yes	440	29	0	30	225	Cold	Yes	Ends Cut	Bottom
29	0	1	30	880	8	.75	Yes	440	43	0	15	225	Cold	No	Whole	Top
30	10	1	30	880	8	.5	No	220	33	30	30	225	Cold	No	Whole	Bottom
31	0	2	30	880	8	.5	No	220	29	0	15	250	Hot	Yes	Whole	Bottom
32	10	2	30	880	8	.75	Yes	440	49	30	30	250	Hot	Yes	Whole	Top

TABLE XL (Concluded)

PREPARATION OF PARALLEL STRAND SPECIMENS
EFFECT OF MATERIAL AND PROCESS VARIABLES WITH PARAPLEX AP-174 RESIN

Specimen Number	Styrene Addition, %	BPO Catalyst Concentration, %	Degas Resin, Minutes	Reinforcement Garan Flinished Yarn or 880 Sized Roving	Number of 8-End Packages Wound at Once	Width of Mold, Inches	Preheat Mold Before Winding	Speed of Winding, Inches Per Minute	Turns on Mold	Degas Wound Mold, Minutes	Time of Cure, Minutes	Temperature of Cure, °F	Remove Hot or Cold After Cure	Postcure 30 Minutes at 250°F	Specimen Preparation for Testing	Top or Bottom Concave in Flexural Test
33	0	2	0	Garan	3	.75	Yes	440	115	0	15	250	Hot	Yes	Ends Cut	Top
34	10	1	30	Garan	3	.5	Yes	440	77	0	30	250	Hot	No	Whole	Bottom
35	10	1	0	880	3	.75	No	440	115	30	15	250	Cold	Yes	Whole	Bottom
36	0	2	30	880	3	.5	No	440	77	30	30	250	Cold	No	Ends Cut	Top
37	0	1	0	Garan	8	.5	No	440	29	30	30	225	Hot	Yes	Whole	Top
38	10	2	30	Garan	8	.75	No	440	43	30	15	225	Hot	No	Ends Cut	Bottom
39	10	2	0	880	8	.5	Yes	440	29	0	30	225	Cold	Yes	Ends Cut	Bottom
40	0	1	30	880	8	.75	Yes	440	43	0	15	225	Cold	No	Whole	Top

possible. This was controlled manually by the operator. The actual number of turns of the mold used to prepare the specimens is shown in Table XLI.

TABLE XLI

NUMBER OF TURNS OF MOLD FOR PARALLEL STRAND BARS WITH PARAPLEX AP-174 RESIN

Number of Packages	Size of Mold	Level 1 "Low Turns"	Level 2 "High Turns"
3	1/2 inch	77	87
	3/4 inch	115	130
8	1/2 inch	29	33
	3/4 inch	43	49

The last comment for this section concerns the tenth variable, degassing the wound mold. When the molds were not degassed, they were not cured immediately. A half hour waiting period was scheduled to give all moldings the same wet-out time.

Variables in Curing Process

Most of the curing variables in Table XXXIX are self-explanatory. The only variable which needs further explanation concerns the way the specimens were removed from the mold. In the case of "Hot" removal the specimens were removed right after the mold was taken out of the press. For "Cold" removal the molds were immediately immersed in cold water after they were taken from the press.

Variables in Testing Process

The "Specimen Preparation for Testing" variable has two levels; "whole" and "ends cut." The level "whole" means that the specimens were tested as they came from the mold with no further preparation. "Ends cut" means that the ends of the specimens were cut before testing.

The other testing variable is "Top or Bottom Concave in Flexural Test." At one level, "Top," the bending force was applied to the side

of the specimen adjacent to the male part of the mold. For the other level, "Bottom," the force was applied to the side of the specimen adjacent to the female part of the mold. This is shown in Figure 13.

Discussion of Results. All original test data are presented in the Appendix, Table LXVIII.

Summary 1. The analysis of the data shows that all dry target properties for this resin finish system were surpassed. The mechanical properties of the best bars are summarized in Table XLII.

TABLE XLII

SUMMARY OF MAXIMUM MECHANICAL PROPERTIES OF PARALLEL STRAND BARS AFTER ANALYSIS OF BALANCED EXPERIMENT
RESIN: PARAPLEX AP-174

	DRY FLEXURAL PROPERTIES						
		Obtained			Obtained		
	Target Strength 10^3 psi	Strength 10^3 psi	Specific Value 10^6 in	Target Modulus 10^6 psi	Modulus 10^6 psi	Specific Value 10^8 in	Glass Vol. (%)
880 Sized Roving	210	265	3.35	7.0	7.81	0.98	74.0
Garan Finished Yarn	210	247	3.18	7.0	8.01	1.03	67.2

2. Several bars for wet flexural testing were damaged in molding and test preparation. These resulted in very low flexural strengths tested after a two hour boil. Although the initial modulus values were accurate, the strengths were insufficient for a reliable analysis. A second experiment was performed to provide accurate wet flexural strength data. This is discussed in a later section beginning on page 177.

3. Over the ranges studied, none of the cure variations affected any mechanical property; thus, any cure system within the

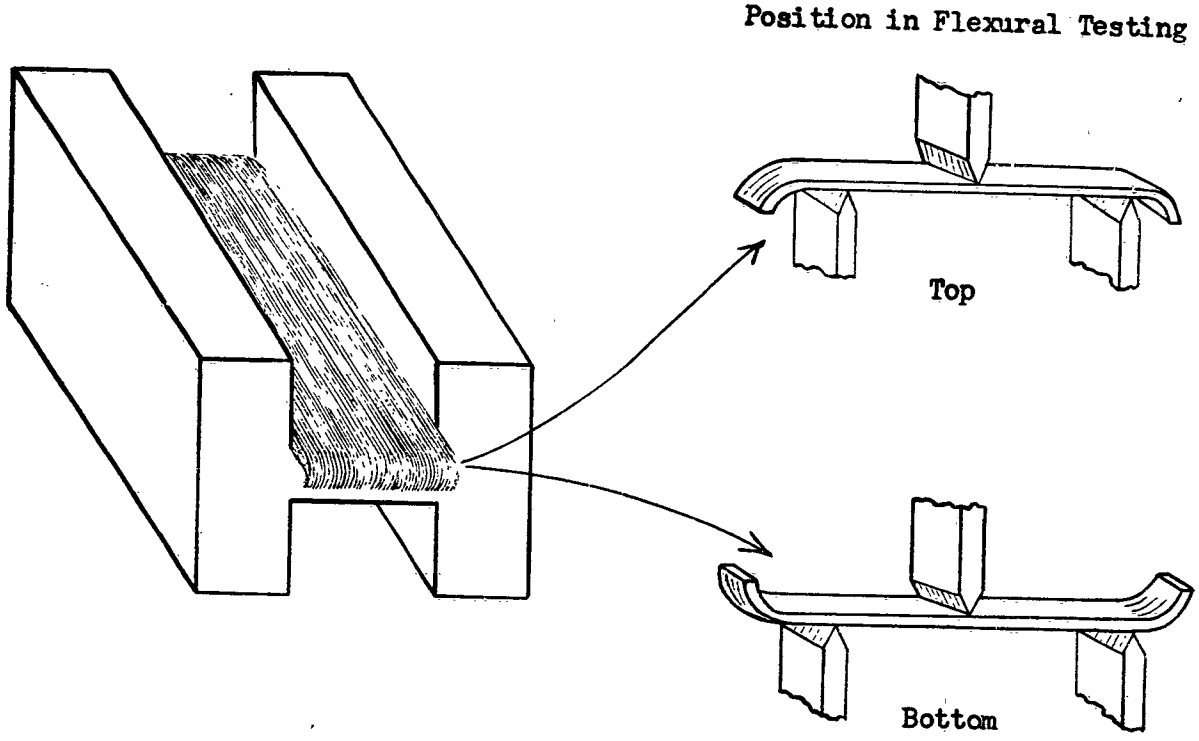

Figure 13 - Two Methods of Testing Parallel Strand Bars in Flexure

following limits should provide essentially the same strengths in a molded specimen.

Catalyst concentration:	1 - 2 per cent BPO
Cure Time:	15 - 30 minutes
Cure Temperature;	225 - 250°F
Post Cure:	None - 30 minutes @ 250°F

Dry Flexural Strength. The following variables significantly affected the dry flexural strength of the bars.

1. The number of packages used for winding the mold.
2. The type of reinforcement used - Garan finished yarn or 880 sized roving.
3. The amount of glass in the specimen.
4. The way of testing the specimen - applying the bending force at the top or bottom of the specimen.

Table XLIII shows that the number of packages used for winding was the variable of greatest influence. Flexural strength was increased about 8% using three packages in place of eight. We believe that by using the guide-eye the glass was packed closer together without air entrapment. This was also concluded from the reed marks observed on the specimens wound with eight packages.

The second most influential variable was the type of glass reinforcement, i.e., 880 sized roving or Garan finished yarn. The actual difference, however, depended on the position of the specimen in the test jig. When the bottom of the specimen was concave in the test (see Figure 13) the specimens reinforced with 880 sized roving were 20,000 to 30,000 psi stronger than the Garan yarn reinforced specimens. There was a much smaller difference between the reinforcements when the top of the specimen was concave in testing.

The same results can be discussed on the basis of the effect of test position. With Garan finished yarn the strength change due to the different test positions was only 1100 psi. This was not considered a significant difference. With 880 sized roving, however, the change in strength due to test position was about 20,000 psi. We believe that the twist of the yarn helped to pack it more evenly and give a more homogenous specimen. The 880 sized roving strands have a negligible amount of twist. Because of this the strands of the peripheral side of the wound mold disoriented themselves and gave a weaker outside surface. When the top side was concave in the flexural test, the compressive stresses were not distributed well causing the specimen to fail prematurely.

The last variable to have an effect on the dry flexural strength was the amount of glass wound on the mold. Between the two levels the

TABLE XLIII

DRY FLEXURAL STRENGTH, 10^3 PSI, OF PARALLEL STRAND BARS
AFTER ANALYSIS OF BALANCED EXPERIMENT
RESIN: PARAPLEX AP-174

No. of Packages	No. of Turns for Parallel Strand Molds		Garan Yarn		880 Sized Roving	
	1/2 inch mold	3/4 inch mold	Top-up in testing	Bottom-up in testing	Top-up in testing	Bottom-up in testing
3	77	115	222	221	236	257
3	87	130	249	246	245	265
8	29	43	203	202	218	238
8	33	49	229	228	226	247
Std. Deviation: 8.0 x 10^3 psi						

change in strength properties was about 25,000 psi for Garan finished yarn and only about 8,500 psi for the 880 sized roving.

Dry Flexural Modulus. The only important variables which affected the dry flexural modulus were:

1. The number of packages used for winding the mold.
2. The amount of glass in the specimen.
3. The width of the mold.
4. The type of reinforcement used - Garan finished yarn or 880 sized roving.

Three of the four important variables (1, 2, and 4) for determining the modulus of the reinforced specimens were the same as the ones affecting the flexural strength. The variable of the testing method, which affected the flexural strength, did not influence the modulus.

A study of Table XLIV shows that the change in flexural modulus going from the eight packages winding method to the three packages winding method was 1.07×10^6 psi. The change was 6 times greater than the standard deviation for this set of data.

The second most influential variable was the amount of glass used for the reinforced specimens. Changing the glass content level resulted in a consistent increase in the dry flexural modulus of 810,000 psi.

The third variable was the width of the mold. A consistent difference of 260,000 psi was observed going from the 1/2 inch mold to the 3/4 inch mold. The reason for this increase in modulus by changing from the 1/2 inch mold to the 3/4 inch mold was the corresponding unintentional increase in glass content. (See discussion below on glass content.) This change in glass content, however, was too small to also cause a change in the flexural strength.

The fourth important variable for the dry flexural modulus was the type of reinforcement - Garan finished yarn or 880 sized roving. A consistent difference of 200,000 psi was observed. The same increase in the dry flexural modulus values was observed both with the 1/2 inch and 3/4 inch molds.

Wet Flexural Properties. Several bars for wet flexural testing were damaged in molding and test preparation. These resulted in very low flexural strengths tested after a two hour boil. A second experiment was performed to provide accurate wet flexural data. This is discussed in the next section beginning on page 176.

Glass Content, Specific Gravity, Ignition Loss. The analysis of the results indicates that the only variables affecting these physical

TABLE XLIV

DRY FLEXURAL MODULUS, 10^6 PSI, OF PARALLEL STRAND BARS
AFTER ANALYSIS OF BALANCED EXPERIMENT
RESIN: PARAPLEX AP-174

No. of Packages	No. of Turns for Parallel Strand Molds		Garan Yarn		880 Sized Roving	
	1/2 inch mold	3/4 inch mold	1/2 inch mold	3/4 inch mold	1/2 inch mold	3/4 inch mold
3	77	115	6.94	7.20	6.74	7.00
3	87	130	7.75	8.01	7.55	7.81
8	29	43	5.87	6.13	5.67	5.93
8	33	49	6.68	6.94	6.48	6.74
Std. Deviation: 0.018 x 10^6 psi						

TABLE XLV

PROPERTIES OF PARALLEL STRAND BARS AFTER ANALYSIS OF BALANCED EXPERIMENT
RESIN: PARAPLEX AP-174

No. of Packages	No. of Turns for Parallel Strand Molds		Glass Content, %		Specific Gravity		Ignition Loss, %	
	1/2 inch mold	3/4 inch mold	1/2 inch mold	3/4 inch mold	1/2 inch mold	3/4 inch mold	1/2 inch mold	3/4 inch mold
Garan Finished Yarn								
3 8	77 29	115 43	59.6	62.2	2.042	2.075	24.40	22.53
3 8	87 33	130 49	66.2	68.3	2.116	2.150	19.22	17.36
880-Sized Roving								
3 8	77 29	115 43	66.0	68.2	2.089	2.122	20.35	18.48
3 8	87 33	130 49	72.7	75.2	2.164	2.197	15.17	13.31

properties were:

1. Number of turns of mold in winding process.
2. Type of reinforcement used - Garan finished yarn or 880 sized roving.
3. Width of the mold.

The effects of these variables are apparent in the data of Table XLV.

The glass content of both size bars was not the same even though 50 per cent more turns were used on the 3/4 inch molds. This was caused by the fact that the cross sectional area of the molded specimens from the 3/4 inch molds were a little less than 50 per cent larger than the area of the molded specimens from the 1/2 inch molds. This was an unintentional difference and was not discovered until after all the bars were molded and tested.

As was expected, no cure variations affected these physical properties. All the differences between the specimens were the results of physical variations in the molding system.

Paraplex AP-174 Resin and 880 Sized Roving - Second Experiment

A second experiment was performed with Paraplex AP-174 resin in order to obtain accurate wet strength data. Since the first experiment showed the superiority of 880 sized roving over Garan finished yarn, the roving alone was included. Four process variables were included in this experiment. These are outlined in Table XLVI.

TABLE XLVI

PROCESS VARIABLES STUDIED WITH PARALLEL STRAND MOLDINGS
RESIN: PARAPLEX AP-174
REINFORCEMENT: 880 SIZED ROVING

Variables	1	vs	2
BPO catalyst content	1%		2%
Number of turns	Low*		High*
Width of mold	1/2 inch		3/4 inch
Postcure	None		1/2 hr @250°F
*See Table XLI.			

Preparation of Specimens

Twelve moldings were prepared with the variables at levels shown in Table XLVII. In addition, the following conditions were used for all moldings:

Resin:	90 parts Paraplex AP-174 plus 10 parts styrene. This mixture was not degassed.
Mold Preparation:	Three packages of 8-end 880 sized roving wound at 44 turns per minute. The complete wound mold was degassed for 1/2 hour under 30 inches of vacuum. (Mercury)
Cure:	30 minutes @225°F.

Discussion of Results: The test data for all moldings are presented in the Appendix, Table LXIX. After analysis, the effect of the critical variables on these properties was tabulated and is presented in Table XLVIII. A discussion follows of the individual property measurements.

Flexural Properties After Two-Hour Boil. The data showed that the only variables affecting the wet flexural properties were:

1. The number of turns.
2. The width of the mold.

The catalyst concentration and the postcure did not affect the wet flexural properties of AP-174 resin reinforced with 880 sized roving. This is in complete agreement with the results obtained for the dry flexural properties in the first experiment.

The target value for wet flexural strength was 185×10^3 psi. This was easily exceeded. A comparison of the wet flexural values in Table XLVIII with the dry properties reported earlier shows excellent per cent strength retention with this resin-finish system.

Glass by Volume. The analysis of the data showed again that the same two variables were affecting the glass content. The reason for the effect of mold size on wet flexural strength and wet flexural modulus is the higher glass content of the laminates from the 3/4 inch.

TABLE XLVII

PREPARATION OF PARALLEL STRAND BARS

RESIN: PARAPLEX AP-174
REINFORCEMENT: 880 SIZED ROVING

Specimen Number	Catalyst Content	Number of Turns	Mold Size	Postcure
1	1%	77	1/2"	None
2	2%	77	1/2"	1/2 hr @ 250°F
3	1%	115	3/4	1/2 hr @ 250°F
4	2%	115	3/4	None
5	1%	87	1/2"	1/2 hr @ 250°F
6	2%	87	1/2"	None
7	1%	130	3/4"	None
8	2%	130	3/4"	1/2 hr @ 250°F
9	1%	77	1/2"	None
10	1%	115	3/4"	1/2 hr @ 250°F
11	2%	87	1/2"	None
12	2%	130	3/4"	1/2 hr @ 250°F

TABLE XLVIII

PROPERTIES OF PARALLEL STRAND BARS AFTER ANALYSIS OF BALANCED EXPERIMENT

RESIN: PARAPLEX AP-174
REINFORCEMENT: 380 SIZED ROVING

Mold Size	No. of Turns	Flexural Properties After Two Hour Boil		Glass Volume (%)
		Strength 10^3 psi	Modulus 10^6 psi	
1/2 Inch	77	213	6.76	66.1
	87	244	7.53	73.7
3/4 Inch	115	239	7.33	69.8
	130	247	7.78	75.1
Standard Deviation of Presented Values		3.0	0.24	1.1

Heat Resistant Resins With "E" Glass

The parallel strand bar molding technique used for specimens with Paraplex AP-174 resin can also be used for heat resistant resins molded by the wet lay-up technique. Development of a non-woven reinforcement preimpregnated with a heat resistant resin is a logical step from the work with the room temperature resin system.

The target properties were concerned only with the development of heat-resistant resin laminates reinforced with "E" glass. The mechanical properties desired from these laminates were:

Flexural strength, dry	180,000 psi
Flexural strength, wet	145,000 psi
Flexural strength after 192 hours at 500°F	80,000 psi
Flexural modulus, dry	6.0×10^6 psi

Three resins were studied, all with varying amounts of success. These are discussed below. The three resins were:

1. Vibrin 136A, heat resistant polyester
2. Unox 207, heat resistant epoxy
3. Epon 828, epoxy, with PMDA hardner

Vibrin 136A, Heat Resistant Polyester Resin

Vibrin 136A is a triallyl cyanurate polyester resin produced by the Naugatuck Chemical Company. It is somewhat unusual among the elevated temperature resins because it can be molded using a wet lay-up technique.

Preparation of Specimens. "E" glass in the form of 8 ends Garan finished 150's 1/0 yarn was used as the reinforcement. The heat cleaning and finishing of the yarn was done after the individual strands were wound together.

The resin was prepared for molding by degassing one hour at 230°F, cooling to 140°F and catalyzing with 0.15 per cent tertiarybutylperbonzate (TBP). After mixing in the catalyst, the resin was degassed again for 15 minutes. The degassing in both cases was done at an absolute pressure of about 1 millimeter of Mercury.

Once the resin was prepared, the molds were wound with impregnated glass yarn following the parallel strand molding technique. The cure cycle was as follows:

Primary Cure:	2 hours at 250°F
Postcure:	1 hour at 400°F
	1 hour at 450°F
	3 hours at 500°F

Discussion of Results. All bars were tested according to the specifications in LP-406-b. These data are presented in Table XLIX.

The highest strength obtained in testing the Vibrin specimens dry was 194,000 psi. This value was above the target value of 180,000 psi. The wet strength value obtained was about 204,000 psi. This value was above the target property of 145,000 psi and in this case was actually above the dry value. It is believed that this is the result of different batches of resin and better temperature control during the postcure.

The high temperature test, one half hour at 500°F, gave lower results than the target strength of 80,000 psi. The highest value obtained was 59,800 psi. Data reported in WADD TR 60-24 with YM31A fabric reinforced Vibrin 136A resin showed about a 50 per cent drop in strength after aging for 192 hours at 500°F. Since the flexural strength did not reach the target strength after 1/2 hour at 500°F, no attempt was made to test these bars after 192 hours.

Epon 828, Epoxy Resin, with PMDA Hardener

The use of pyromelliticdianhydride (PMDA hardener) with Epon 828 resin has resulted in promising results using the wet lay-up technique with fabric laminates.[1] All PMDA from the present manufacturing facilities is approximately 95 per cent less than 10 microns in particle size. This material forms very stable dispersions in liquid epoxy resins and results in essentially complete reaction of the curing agent with the resin.

Preparation of Specimens. An attempt to use this system with the parallel strand molding technique was only partially successful. The Epon 828/PMDA dispersion was very resistant to flow. During the cure cycle, the mold could not be closed to stops. The resultant specimens were very porous and contained only about 45 per cent glass by volume. The bars were molded as follows:

Resin:	Epon 828, epoxy
Hardener:	31.2 pph PMDA
Reinforcement:	801 sized roving

[1] R. O. Menard and W. W. Cooner. Epoxy Resin Laminates with High Thermal Resistance, (Penns Grove, New Jersey: E. I. DuPont De Nemours and Co., Inc.)

TABLE XLIX

PROPERTIES OF PARALLEL STRAND BARS
RESIN: VIBRIN 136A
REINFORCEMENT: GARAN FINISHED "E" GLASS YARN

Spec. No.	Turns on Mold	Flexural Properties						Ignition Loss %	Spec. Grav.	Glass Volume %
		Strength, 10^3 psi			Modulus, 10^6 psi					
		Dry	2-Hour Boil	1/2 Hr. @ 500°F	Dry	2-Hour Boil	1/2 Hr. @ 500°F			
1	360	194.0	-	-	7.79	-	-	20.9	2.12	65.8
2	375	117.6	-	-	7.41	-	-	19.7	2.13	67.0
3	390	125.1	-	-	7.58	-	-	17.6	2.12	68.3
4	340	-	199.0	53.6	-	7.12	5.77	25.0	2.06	).8
5	350	-	193.5	55.0	-	6.84	6.10	23.6	2.09	62.8
6	360	-	204.0	57.0	-	7.14	6.18	21.8	2.12	65.0
7	370	-	203.5	46.7	-	7.20	6.44	20.7	2.13	66.2

Cure: 1 hour at 380°F
Postcure: 24 hours at 450°F

The test results for this resin system were far below the target properties. Table L shows the test data which were obtained.

TABLE L

PROPERTIES OF PARALLEL STRAND BARS
RESIN: Epon 828/PMDA
REINFORCEMENT: 880 Sized Roving

Turns on Mold	Flexural Properties				Glass Vol. %
	Strength, 10^3 psi		Modulus, 10^6 psi		
	After Two Hour Boil	After 1/2 Hr @500°F	After Two Hour Boil	After 1/2 Hr @500°F	
110	41.1	7.11	4.19	0.65	45.1
120	71.7	8.40	4.63	0.96	47.7
130	38.3	8.39	4.35	1.11	45.1

Because of the difficulty in obtaining a solid non porous specimen, this resin system was dropped from further consideration.

Unox 207, Epoxy Resin

Unox 207 is an epoxy resin manufactured by Union Carbide Chemicals Company. Dicyclopentadiene dioxide (Unox 207) is a potentially inexpensive diepoxide which melts at 184°C. Despite the high melting point, the diepoxide is soluble in near-stoichiometric quantities of certain hardener such as maleic anhydride and gives mixtures melting at or near room temperature. The addition of a third component, a polyol initiator,

to mixtures of dicyclopentadiene dioxide and maleic anhydride increases the rate of cure markedly.[1]

A resin mix was prepared as follows:

Unox 207:	63.3 per cent by weight
Maleic anhydride:	30.0 per cent by weight
Trimethylolpropane:	6.7 per cent by weight

Roving with 801 size was used as the reinforcement. The viscosity temperature relationship was such that during molding, the resin ran out of the mold and resulted in resin starved specimens. These specimens could not be tested because of this lack of structural integrity. Further work with the resin was discontinued.

Paraplex AP-174 Resin With YM31A Glass

Preparation of Specimens. The strengths of parallel strand molded bars were used to evaluate the best resin from the initial screening study, Paraplex AP-174, with YM31A glass. 880 size was not available as a surface treatment for YM31A glass; hence, another silane size (830) was used. Parallel strand bars were also molded with 08 treatment as the surface treatment for YM31A glass. The molding conditions were as follows:

Catalyst:	1 per cent benzoyl peroxide crystals
Resin:	90 parts Paraplex AP-174 plus 10 parts styrene
Reinforcement:	YM31A glass
Primary Cure:	15 minutes @230°F
Postcure:	None

Discussion of Results. The properties of these bars are shown in Table LI. These data are also presented in Table XXIX in Phase II under the discussion of the behavior of YM31A glass in reinforced plastics. The strengths of Paraplex AP-174 bars reinforced with 08 treated YM31A glass yarn surpassed all target properties.

These results with the 830 sized roving are the lowest values ever obtained with YM31A glass reinforced parallel strand bars. However, the experience of past work presented in this report has almost always led to disapproval of YM31A reinforced polyesters using silane surface treatments. In the case of 830 sized roving, the silane itself and the other ingredients in the forming size are helping to produce the

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[1]C. W. McGary, Jr., C. T. Patrick, Jr. High Temperature Epoxy Resins, (New York: Union Carbide Chemicals Company)

TABLE LI

PROPERTIES OF PARALLEL STRAND BARS
RESIN: Paraplex AP-174
REINFORCEMENT: YM31A Glass

Reinforcement	Dry Flexural Properties						Glass Volume %
	STRENGTH			MODULUS			
		Obtained			Obtained		
	Target	Actual Value	Specific Value	Target	Actual Value	Specific Value	
	10^3 psi	10^3 psi	10^6 in	10^6 psi	10^3 psi	10^8 in	
08 Treated Yarn	210	268	3.27	10.5	10.8	1.31	65.4
830 Sized Roving	210	131	1.61	10.5	10.0	1.23	64.0
08 Treated Yarn	185	210	2.56	--	10.7	1.30	65.4
830 Sized Roving	185	79	0.97	--	8.3	1.02	64.0

poor results relative to those obtained with 08 treated yarn. We do not recommend any silane size for use with YM31A roving and polyester resins.

A comparison of the strongest bars with Paraplex AP-174 and both glass compositions is given in Table LII. The units for the specific values are psi/lb/in^3.

An examination of Table LII shows that the dry specific strengths are essentially equal for both glasses and all specific moduli are about 30 per cent higher with YM31A glass. The wet specific strength is the only property which shows a decrease with YM31A glass. A more complete study of surface treatment for YM31A molded with Paraplex AP-174 resin should result in bars with wet strengths closer to wet strengths of bars with "E" glass. Also, better comparisons would result with the systems already reported if bars were molded with similar glass contents.

TABLE LII

SPECIFIC VALUES OF BEST PARALLEL STRAND BARS "E" GLASS VS YM31A GLASS WITH PARAPLEX AP-174

Glass Composition	Surface Treatment	Flexural Properties				Glass Volume %
		Strength Specific Value 10^6 in		Modulus Specific Value 10^6 in		
		Dry	2 Hr Boil	Dry	2 Hr Boil	
YM31A	08 Treated Yarn	3.27	2.56	1.31	1.30	65.4
"E"	880 Sized Yarn	3.35	3.11	1.03	0.98	74.0

Winding and Packaging The Preimpregnated Reinforcement

Several methods for winding and packaging parallel strands impregnated with Paraplex AP-174 were investigated. Although this investigation was done on a fairly small scale, it did indicate the feasibility of winding and storing a wet lay-up polyester resin.

Discussion of Results. The first method consisted of passing strands through a resin filled dip tank and winding onto a circular spool. Each layer was separated with a strip of cellophane. Enough glass (64 ends of 150's 1/0 yarn) was used so that a one half inch wide tape could be wound. After storage at room temperature for two weeks, enough of the styrene evaporated so that the material was only very slightly tacky. It separated well from the cellophane.

Another spool was wound using the method described above, but this time the spool was wrapped in a polyethylene bag to prevent evaporation. The apparatus for winding this spool is shown in Figure 14. Parallel strand bars were molded at intervals for five weeks. During this time the spool was stored at room temperature. After the five week period, the resin had partially gelled, resulting in defective bars. These bars were not tested for structural properties - acceptability was judged on the basis of visual appearance.

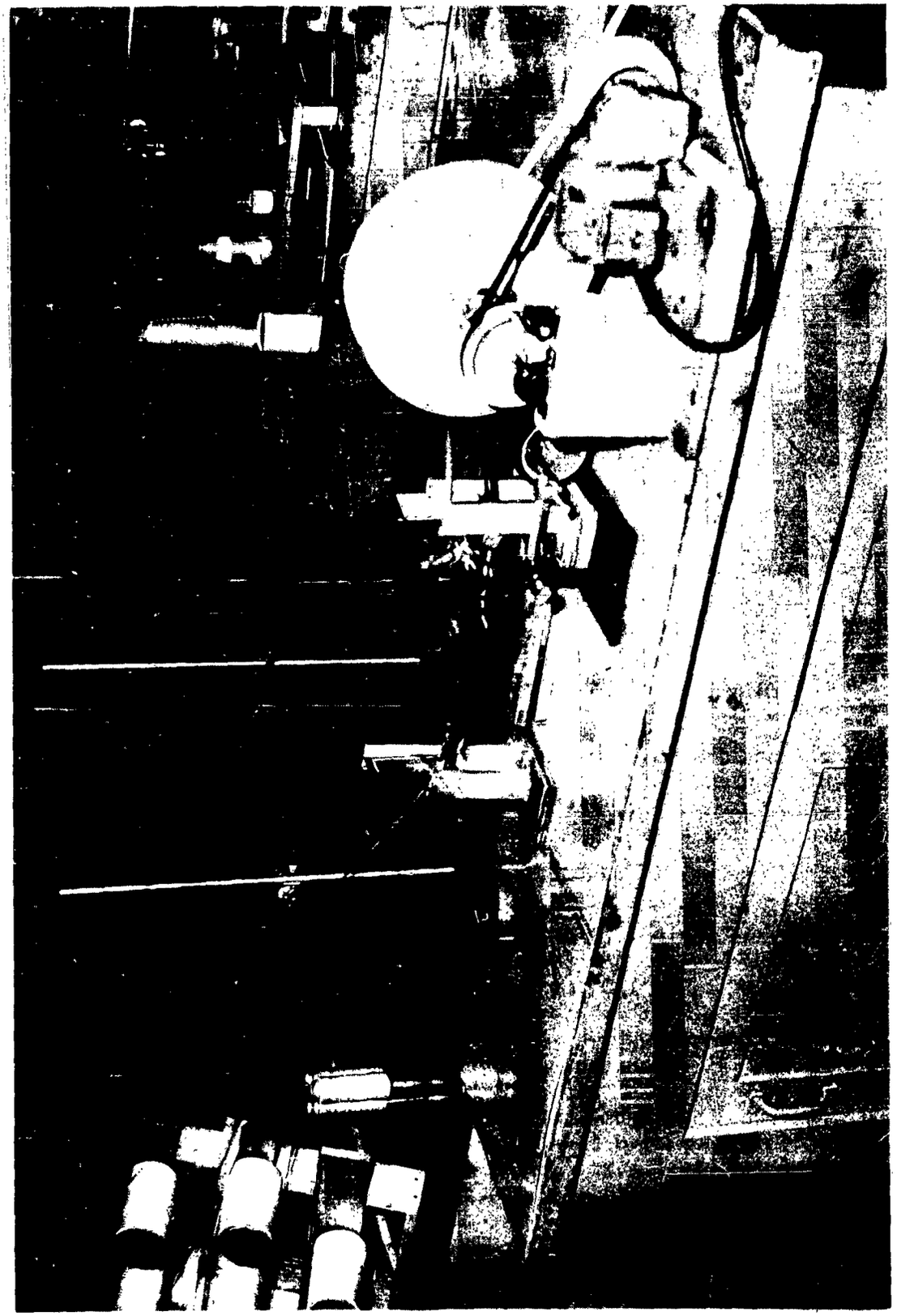

Figure 14 - Winding Equipment

The second method utilized a thixotropic material (Cabosil) as a means of reducing the tackiness of the wet strand. No improvement was noted in the handling characteristics of the material. The Cabosil was introduced to the system, both by dispersion in the resin and by sprinkling it on the strand after it had been impregnated with the resin. This method was eliminated from further consideration.

The third method consisted of immersing a one half pound package of yarn in a resin bath and impregnating the reinforcement without rewinding. The package of yarn and the resin bath were degassed for fifteen minutes while impregnation was taking place. This removed air from the package and allowed complete wet-out. After thorough impregnation, the package was wrapped in cellophane and stored at room temperature. Moldings were made from this impregnated package after one and two week intervals. Although there was no separation between adjacent layers on this package as in the methods described above, a single end could be unwound without difficulty. The flow characteristics were good and parallel strand bars were wound and cured normally. These bars were not tested for mechanical properties. Acceptability was judged purely on a visual appearance basis.

Scale-Up of Parallel Strand Molding Technique

One of the disadvantages of the bar molding technique presently employed is the size of the specimens. At the present time only flexural and compression tests can be performed on the 3/4 by 4 by 1/8 inch specimens.

A new mold was designed for preparation of larger specimens. This mold design is shown in Figures 15 and 16. Basically it is a scale-up in size of the present mold. It will prepare two flat specimens in a single molding, each specimen being 6 by 12 by 1/8 inches. This allows sufficient area of molded specimen to test all mechanical properties that will be applicable to a flat parallel strand laminate. This mold is presently being built.

Winding equipment to handle this mold was also designed and is presently being constructed. Either impregnated strands or narrow width tape will be wound as the mold itself is turning and will allow the layup to be completed with very little strand crossing.

CONCLUSIONS AND RECOMMENDATIONS

Room Temperature Resins With "E" Glass

Paraplex AP-174, polyester resin, was the strongest matrix material studied, based on the flexural properties of parallel strand bars. This

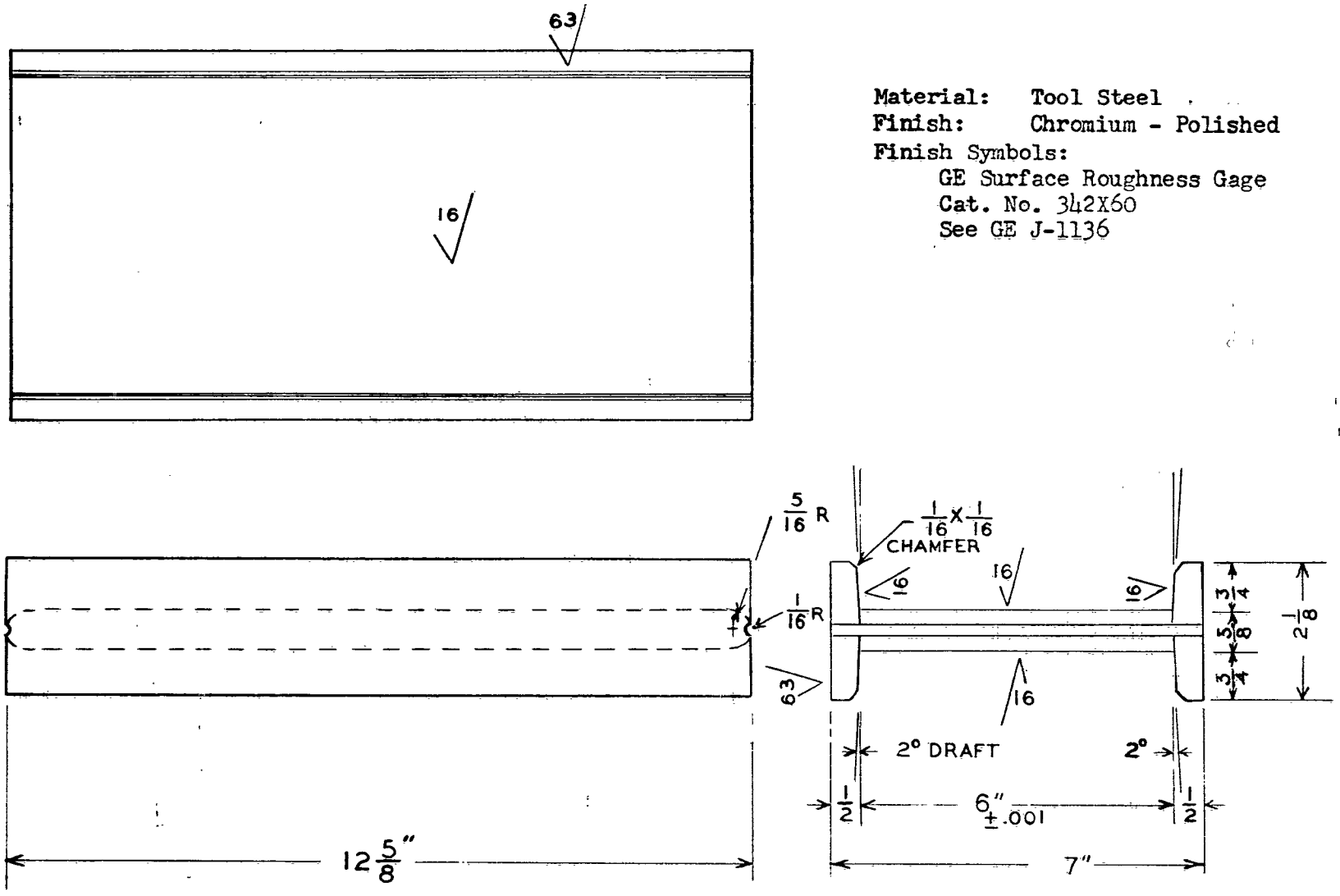

Figure 15 - Parallel Strand Specimen Mold: Double Female Section (1 required)

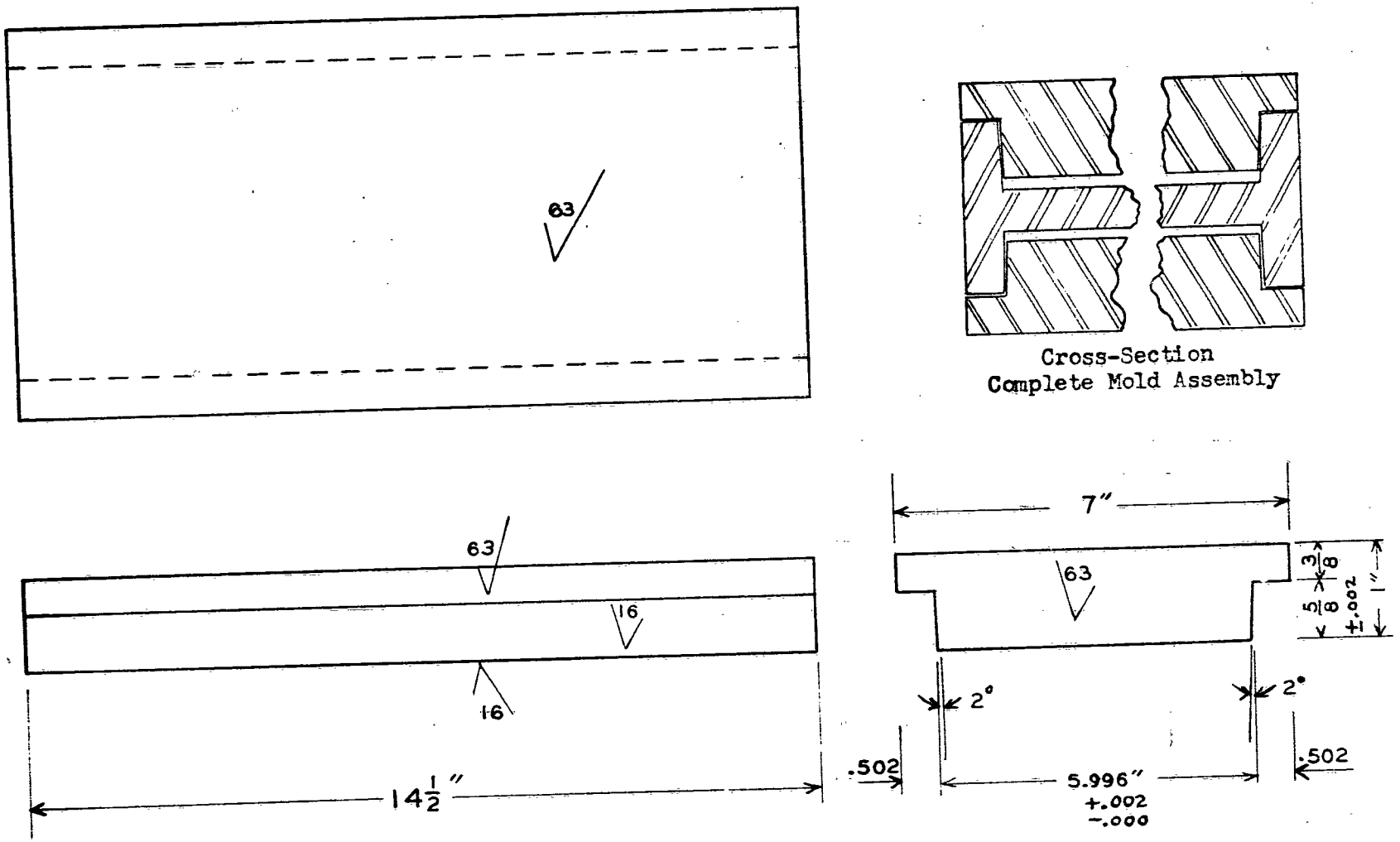

Figure 16 - Parallel Strand Specimen Mold: Male Mold Section (2 required)
(See Figure 15 for Material and Finish Data)

work should be supplemented with a more thorough screening of surface treatments on the glass as well as more thorough testing of different mechanical properties. At the present time 880 sized roving is recommended for use with this resin.

The optimum glass content for a parallel strand specimen depends on both the adhesion of the glass to the resin and the alignment of the strands in the specimen itself. The glass content which results in the strongest bars is different for each resin finish system. For highest flexural strengths, the optimum glass content with AP-174 resin and 880 sized roving is 72-75 per cent by volume, or 85-87 per cent by weight.

Heat Resistant Resins With "E" Glass

Vibrin 136A, heat resistant polyester resin, reinforced with Garan finished yarn resulted in parallel strand bars which met the target properties for dry and wet flexural properties. These bars, however, did not meet the target property for heat resistance. More work should be done to investigate other resins for heat resistance which can be molded by the wet layup, parallel strand process.

Room Temperature Resins With YM31A Glass

Parallel strand bars reinforced with YM31A glass can be molded which are stronger than similar moldings with "E" glass. With Paraplex AP-174 resin as the matrix material dry specific flexural strengths with the two glasses were equivalent and specific modulus values were 30 per cent higher, comparing YM31A glass to "E" glass. Although the specific wet flexural strength was lower with YM31A glass than "E" glass, we believe that a thorough screening of resin compatible surface treatments would show results which are equivalent for the two glasses.

Winding and Packaging the Preimpregnated Product

Glass strands impregnated with catalyzed Paraplex AP-174 are moldable after storage at room temperature for a period of at least three weeks. Physical properties of bars molded at one week intervals in a five week storage experiment were not run and this conclusion is based on the visual appearance of the molded bars and behavior of the impregnated strand. The experiment should be repeated and the appropriate physical properties measured at intervals up to five weeks in order to determine the practical limit of storage time with greater exactness.

A series of yarns, which are impregnated and rewound on a spool, can provide a narrow tape for future molding. A cellophane strip between layers may help to prevent layers from intermingling but it is unnecessary from the standpoint of resin tackiness.

A new mold and winding equipment are being built to provide a larger parallel strand specimen. This equipment should be used to prepare moldings for the evaluation of parallel strand systems with YM31A glass.

A P P E N D I X

TABLE LIII

PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS

FINISH: A-172
RESIN: PARAPLEX P-43

Specimen Number	Wet Flexural Strength 10^3 psi	Wet Flexural Modulus 10^6 psi	Ignition Loss %	Glass by Volume %	Specific Gravity
1	45.6	2.83	42.4	38.3	1.71
2	40.2	3.36	36.5	42.1	1.92
3	45.2	2.76	42.6	39.0	1.73
4	42.8	3.27	36.2	41.9	1.90
5	45.1	2.95	42.0	39.4	1.73
6	40.7	3.43	34.9	43.2	1.92
7	43.6	2.91	43.4	38.0	1.71
8	42.5	3.35	35.8	42.5	1.91
9	45.7	2.83	43.1	38.2	1.71
10	39.0	2.61	36.3	42.0	1.91
11	45.4	2.82	41.6	39.8	1.74
12	43.4	3.57	34.6	43.6	1.93
13	46.8	2.86	42.1	39.2	1.73
14	41.4	2.77	33.9	44.1	1.93
15	39.9	2.76	42.7	38.7	1.72
16	38.9	2.85	36.0	42.1	1.90

TABLE LIV

PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS TAPE

FINISHES: VOLAN A AND GARAN
RESIN: PARAPLEX P-43

Specimen Number	Wet Flexural Strength 10^3 psi	Wet Flexural Modulus 10^6 psi	Ignition Loss %	Glass by Volume %	Specific Gravity
1	47.4	2.94	41.3	40.3	1.75
2	36.0	3.08	35.7	42.2	1.90
3	36.6	3.16	35.4	43.0	1.92
4	48.8	2.03	40.4	41.2	1.76
5	45.2	2.88	40.5	41.0	1.75
6	38.5	2.84	35.2	43.0	1.91
7	45.4	3.38	35.6	42.4	1.90
8	42.0	2.76	41.5	39.9	1.74
9	38.3	3.32	34.9	43.2	1.92
10	47.2	2.94	41.3	40.2	1.74
11	50.7	2.94	40.6	40.8	1.75
12	39.5	3.39	36.2	42.0	1.90
13	38.8	3.20	34.6	43.2	1.91
14	46.2	2.78	41.8	39.6	1.74
15	43.2	2.67	40.2	41.2	1.76
16	46.8	3.54	35.2	43.0	1.92

TABLE LV

PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS

FINISHES: VOLAN A AND A-1100
RESIN: EPON 828

Specimen Number	Wet Flexural Strength 10^3 psi	Wet Flexural Modulus 10^6 psi	Wet Compressive Strength 10^3 psi	Wet Compressive Modulus 10^6 psi	Ignition Loss %	Glass by Volume %	Specific Gravity
1	58.0	2.76	33.6	2.70	42.4	38.2	1.69
2	68.4	3.67	37.0	3.23	38.2	39.5	1.85
3	51.8	2.79	44.2	3.29	42.0	38.5	1.69
4	63.1	2.46	37.2	4.78	38.0	39.6	1.84
5	61.9	2.74	45.5	3.38	41.9	38.6	1.70
6	63.2	3.52	38.8	4.21	37.0	40.7	1.87
7	55.5	2.72	41.4	3.83	42.8	38.0	1.69
8	72.9	3.73	45.5	4.86	40.4	38.1	1.84
9	56.0	2.66	35.0	3.41	41.4	39.4	1.72
10	72.2	3.71	45.2	4.56	39.2	38.8	1.84
11	55.5	2.71	41.5	3.25	41.9	39.0	1.72
12	66.8	4.06	35.2	4.67	35.4	42.6	1.91
13	57.8	2.64	43.0	2.62	43.8	37.2	1.68
14	58.6	3.76	32.5	4.82	37.7	40.3	1.87
15	54.3	2.76	36.3	3.11	43.4	37.6	1.70
16	67.0	3.67	42.8	4.55	37.9	39.9	1.87

TABLE LVI

THE EFFECT OF GLASS BY VOLUME ON PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" AND YM31A GLASS TAPE

FINISH: A-1100
RESIN: EPON 828/CL

Glass	Glass by Volume %	Flexural Strength 10^3 psi	Flexural Modulus 10^6 psi	Compressive Strength 10^3 psi	Compressive Modulus 10^6 psi
"E"	36.5	46.5	2.66	40.5	2.89
	37.0	49.8	2.65	40.7	2.58
	39.9	54.1	2.87	43.0	2.55
	40.5	54.5	2.97	43.1	3.34
	42.8	49.7	3.11	43.4	4.07
YM31A	35.6	52.5	3.37	36.2	4.14
	38.4	62.8	3.72	35.6	4.49
	40.1	62.5	4.05	37.6	4.65
	42.1	63.6	3.93	37.9	4.83
	44.3	66.3	4.06	38.8	4.78

TABLE LVII

EFFECT OF VARYING RESIN STRENGTH AND MODULUS ON PARALLEL STRAND AND TAPE REINFORCEMENT USING "E" AND YM31A GLASS

Glass	Reinforcement Used	Resin Blend Paraplex P-444/ Paraplex P-13	Dry Flexural Strength 10^3 psi	Dry Flexural Modulus 10^6 psi	Glass by Volume (%)
"E"	Parallel Strand	100/0	218.8	7.89	68.5
"E"	Parallel Strand	70/30	160.5	7.48	68.6
"E"	Parallel Strand	50/50	82.4	6.69	68.9
YM31A	Parallel Strand	100/0	210.0	8.25	52.6
YM31A	Parallel Strand	70/30	138.3	7.79	51.8
YM31A	Parallel Strand	50/50	72.4	6.78	53.1
YM31A	Parallel Strand	100/0	222.9	11.6	68.7
YM31A	Parallel Strand	70/30	160.9	11.0	70.5
YM31A	Parallel Strand	50/50	112.6	10.5	68.5
"E"	Tape (128 Weave)	100/0	60.6	3.08	40.4
"E"	Tape (128 Weave)	70/30	46.7	2.65	40.3
"E"	Tape (128 Weave)	50/50	29.6	2.14	40.6
YM31A	Tape (128 Weave)	100/0	57.4	3.77	42.3
YM31A	Tape (128 Weave)	70/30	45.3	3.46	42.2
YM31A	Tape (128 Weave)	50/50	29.5	2.58	43.1

TABLE LVIII

PROPERTIES OF BAR MOLDINGS REINFORCED WITH "E" OR YM31A GLASS TAPE

FINISHES: VOLAN A AND A-1100
RESIN: CTL 91-LD PHENOLIC RESIN

Number Specimen	Wet Flexural Strength, 10^3 psi	Wet Flexural Modulus, 10^6 psi	Glass by Vol. (%)	Ignition Loss (%)	Specific Gravity
1	58.2	3.47	50.7	30.9	1.87
2	78.7	4.92	51.5	27.3	2.05
3	66.1	3.47	50.9	31.0	1.88
4	70.6	4.99	53.1	26.2	2.08
5	69.9	3.52	52.0	30.4	1.91
6	84.9	5.03	52.6	26.7	2.07
7	57.0	3.28	48.5	32.0	1.82
8	60.5	4.73	52.5	26.1	2.05

TABLE LIX

THE EFFECT OF REINFORCEMENT STRUCTURE ON LAMINATE PROPERTIES
USING "E" OR YM31A GLASS YARN

RESIN: PARAPLEX P-43
FINISH: VOLAN A OR 08 TREATMENT

Type Reinforcement →	128 Style Fabric		181 Style Fabric		143 Style Fabric		Parallel Strand	
Glass Type →	"E"	YM31A	"E"	YM31A	"E"	YM31A	"E"	YM31A
Dry Flexural Strength x 10^3 psi	—	—	71.8	59.2	109.1	120.1	—	—
Specific Strength x 10^6 in.	—	—	1.14	0.83	1.62	1.67	—	—
Wet Flexural Strength x 10^3 psi	47.7*	45.9*	64.4	49.1	68.9	84.2	143.5	186.3
Specific Strength x 10^6 in.	0.76	0.66	1.02	0.68	1.03	1.17	1.88	2.23
Dry Compressive Strength x 10^3 psi	—	—	47.8	52.4	55.0	60.8	—	—
Specific Strength x 10^6 in.	—	—	0.76	0.73	0.82	0.85	—	—
Wet Compressive Strength x 10^3 psi	—	—	42.3	35.2	28.2	25.6	—	—
Specific Strength x 10^6 in.	—	—	0.67	0.49	0.42	0.36	—	—
Dry Flexural Modulus x 10^6 psi	—	—	3.33	4.17	6.40	7.72	—	—
Specific Modulus x 10^8 in.	—	—	0.53	0.58	0.95	1.08	—	—
Wet Flexural Modulus x 10^6 psi	2.87	3.24	3.20	3.10	5.77	7.37	7.38	9.91
Specific Modulus x 10^8 in.	0.46	0.47	0.51	0.43	0.86	1.03	0.97	1.18

*Predicted values obtained from Garan-Volan experiment using Paraplex P-43.

TABLE LIX (Concluded)

THE EFFECT OF REINFORCEMENT STRUCTURE ON LAMINATE PROPERTIES USING "E" OR YM31A GLASS YARN

RESIN: PARAPLEX P-43
FINISH: VOLAN A OR 08 TREATMENT

Type Reinforcement →	128 Style Fabric		181 Style Fabric		143 Style Fabric		Parallel Strand	
Glass Type →	"E"	YM31A	"E"	YM31A	"E"	YM31A	"E"	YM31A
Dry Compressive Modulus x 10^6 psi	---	---	2.49	2.87	6.43	8.84	---	---
Specific Modulus x 10^8 in.	---	---	0.40	0.40	0.96	1.23	---	---
Wet Compressive Modulus x 10^6 psi	---	---	2.36	2.82	6.36	8.53	---	---
Specific Modulus x 10^8 in.	---	---	0.38	0.39	0.95	1.18	---	---
Glass by Volume %	40.5	42.7	45.5	45.4	56.0	53.0	68.8	68.0
Specific Gravity	1.75	1.91	1.76	1.99	1.86	1.99	2.11	2.32
Thickness (inches)	0.115	0.116	0.128	0.125	0.095	0.093	0.122	0.124

TABLE LX

THE EFFECT OF REINFORCEMENT STRUCTURE ON LAMINATE PROPERTIES
USING "E" OR YM31A GLASS YARN

RESIN: EPON 828
FINISH: A-1100

Type Reinforcement →	128 Style Fabric		181 Style Fabric		143 Style Fabric		Parallel Strand	
Glass Type →	"E"	YM31A	"E"	YM31A	"E"	YM31A	"E"	YM31A
Dry Flexural Strength x 10^3 psi	57.7	72.1	86.0	94.5	127.5	155.2	---	---
Specific Strength x 10^6 in.	0.95	1.09	1.29	1.32	1.82	2.04	---	---
Wet Flexural Strength x 10^3 psi	50.5	60.7	71.2	84.1	108.7	130.7	225.8	252.5
Specific Strength x 10^6 in.	0.83	0.92	1.07	1.18	1.55	1.72	2.97	3.04
Dry Compressive Strength x 10^3 psi	39.3	42.2	60.5	69.4	66.4	78.3	---	---
Specific Strength x 10^6 in.	0.64	0.64	0.91	0.97	0.95	1.03	---	---
Wet Compressive Strength x 10^3 psi	35.6	33.5	62.4	61.4	49.5	50.5	---	---
Specific Strength x 10^6 in.	0.58	0.51	0.93	0.86	0.71	0.67	---	---
Dry Flextural Modulus x 10^6 psi	2.81	3.83	3.29	4.31	5.83	7.96	---	---
Specific Modulus x 10^8 in.	0.46	0.58	0.49	0.60	0.83	1.05	---	---
Wet Flextural Modulus x 10^6 psi	2.60	3.51	3.55	4.35	5.48	7.85	7.62	10.26
Specific Modulus x 10^8 in.	0.43	0.53	0.53	0.61	0.78	1.03	1.00	1.24
Dry Compressive Modulus x 10^6 psi	3.51	4.78	4.61	6.29	6.02	8.63	---	---
Specific Modulus x 10^8 in.	0.58	0.72	0.69	0.88	0.86	1.14	---	---

TABLE LX (Concluded)

THE EFFECT OF REINFORCEMENT STRUCTURE ON LAMINATE PROPERTIES
USING "E" OR YM31A GLASS YARN

RESIN: EPON 828
FINISH: A-1100

Type Reinforcement →	128 Style Fabric		181 Style Fabric		143 Style Fabric		Parallel Strand	
Glass Type →	"E"	YM31A	"E"	YM31A	"E"	YM31A	"E"	YM31A
Wet Compressive Modulus x 10^6 psi	3.21	4.58	4.96	6.28	6.25	8.78	---	---
Specific Modulus x 10^8 in.	0.53	0.69	0.74	0.88	0.89	1.16	---	---
Glass by Volume	39.2	40.6	53.8	51.5	57.7	55.9	67.0	67.3
Specific Gravity	1.69	1.82	1.84	1.98	1.94	2.10	2.10	2.30
Thickness (inches)	0.121	0.121	0.122	0.122	0.102	0.094	0.124	0.123

TABLE LXI

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: PARAPLEX P-43

Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
880 Sized Roving									
168	2.56	5.30	0.81	47.9	1.82	54.6	0.83	47.9	1.82
163	2.40	5.74	0.84	51.8	1.88	60.4	0.89	51.8	1.88
186	2.59	6.42	0.89	58.8	1.99	61.3	0.85	58.8	1.99
197	2.74	6.73	0.94	61.5	1.99	55.3	0.77	61.5	1.99
221	3.03	7.54	1.03	65.2	2.02	45.7	0.63	65.2	2.02
211	2.77	7.61	1.00	70.9	2.11	46.9	0.62	70.9	2.11
						43.8	0.59	70.6	2.04
08 Treated Yarn									
184	2.61	6.04	0.86	53.5	1.95	97.5	1.41	53.3	1.92
191	2.67	6.34	0.89	56.9	1.98	100.8	1.40	56.9	1.99
201	2.76	6.83	0.94	59.3	2.02	82.8	1.15	59.3	2.00
197	2.65	7.04	0.95	61.5	2.06	81.9	1.13	61.5	2.01
215	2.81	7.50	0.98	66.4	2.12	68.9	0.91	66.4	2.09
169	2.14	7.98	1.01	73.3	2.19	31.5	0.40	73.3	2.18

TABLE LXI (Concluded)

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: PARAPLEX P-43

Garan Finished Yarn									
Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
171	2.58	5.79	0.87	50.3	1.84	85.8	1.29	50.3	1.84
207	2.81	7.06	0.96	62.5	2.04	81.8	1.11	62.5	2.04
223	3.00	7.50	1.01	65.4	2.06	71.2	0.96	65.4	2.06
75	0.98	6.99	0.92	70.2	2.11	59.4	0.78	70.2	2.11

TABLE LXII

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: PARAPLEX AP-174

880 Sized Roving									
Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
233	3.20	6.59	0.90	61.9	2.02	47.6	0.66	59.5	1.99
229	3.14	6.55	0.90	61.9	2.02	36.8	0.52	58.9	1.97
276	3.59	8.02	1.04	71.4	2.13	26.8	0.36	67.0	2.08
240	3.12	7.78	1.01	71.4	2.13	35.1	0.46	68.0	2.13
118	1.88	7.86	0.00	74.7	2.18				
89	1.13	2.99	0.38	74.7	2.18				
Garan Finished Yarn									
223	3.04	6.77	0.87	60.9	2.03	90.8	1.21	64.2	2.08
223	3.04	6.72	0.92	60.9	2.03	107.7	1.43	64.3	2.08
247	3.26	7.53	0.99	67.3	2.10	80.8	1.05	71.0	2.13
238	3.14	7.52	0.99	67.3	2.10	74.2	0.96	69.7	2.13
245	3.12	7.87	1.00	72.1	2.17				
218	2.78	7.77	0.99	72.1	2.17				
110	1.42	7.12	0.92	72.5	2.14				
84	1.09	2.96	0.38	72.5	2.14				

TABLE LXIII

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: EPON 828/CL

801 Sized Roving									
Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
Dry Properties						Dry Properties			
163	2.52	5.53	0.86	49.0	1.79	63.6	0.97	51.5	1.81
165	2.52	5.62	0.86	51.5	1.81	66.1	0.94	59.9	1.94
178	2.61	6.26	0.92	56.1	1.89	64.1	0.89	66.0	2.00
187	2.67	6.49	0.93	59.9	1.94	45.5	0.59	73.3	2.14
191	2.63	6.87	0.95	63.1	2.01				
208	2.88	7.49	1.04	66.0	2.00				
222	2.96	7.79	1.04	69.3	2.08				
107	1.38	7.35	0.95	73.3	2.14				
2 Hour Boil Wet									
161	2.49	5.75	0.89	49.0	1.79				
181	2.65	6.40	0.94	56.1	1.89				
191	2.63	7.16	0.99	63.1	2.01				
197	2.62	7.84	1.04	69.3	2.08				

TABLE LXIII (Concluded)

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: EPON 828/CL

08 Treated Yarn									
Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
Dry Properties						Dry Properties			
162	2.46	4.97	0.76	47.0	1.82	88.2	1.32	48.0	1.85
167	2.43	5.81	0.85	50.1	1.90	87.9	1.31	49.0	1.85
173	2.52	6.36	0.93	52.2	1.90	93.6	1.35	53.5	1.92
181	2.61	6.35	0.92	54.1	1.92	90.4	1.28	54.6	1.95
192	2.67	6.14	0.85	58.4	1.99	76.3	1.06	58.4	2.00
204	2.82	7.34	1.02	59.4	2.00	91.2	1.27	59.4	1.99
194	2.63	6.96	0.94	62.2	2.04	95.4	1.30	62.5	2.03
209	2.78	7.99	1.06	63.9	2.08	92.4	1.26	63.0	2.03
214	2.93	7.52	1.08	62.9	2.02	98.3	1.35	61.7	2.01
224	2.95	8.04	1.06	67.2	2.10	93.6	1.23	67.9	2.10
226	3.04	7.72	1.04	65.0	2.06	72.3	0.97	64.2	2.06
225	2.88	8.38	1.07	70.0	2.16	92.5	1.20	69.4	2.14
229	3.02	8.05	1.06	68.0	2.10	103.9	1.37	70.5	2.10
234	3.01	8.49	1.09	70.7	2.15	82.6	1.06	71.0	2.15
						85.3	1.09	73.6	2.17
236	2.94	8.87	1.11	77.0	2.22	69.8	0.87	76.1	2.21

TABLE LXIV

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: ATLAC 382X WITH 10% METHACRYLIC ACID

Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
880 Sized Roving									
177	2.50	6.17	0.88	58.5	1.96	36.5	0.50	63.3	2.03
163	2.30	5.97	0.84	58.5	1.96	31.4	0.43	63.6	2.03
193	2.51	7.17	0.94	70.0	2.12	44.9	0.59	70.8	2.12
190	2.49	7.33	0.96	70.0	2.12	35.4	0.46	71.3	2.12
192	2.52	7.39	0.97	71.1	2.11				
66	0.86	6.30	0.83	71.1	2.11				
Garan Finished Yarn									
199	2.74	6.87	0.95	61.3	2.01	95.0	1.30	63.3	2.02
197	2.71	6.97	0.96	61.3	2.01	100.7	1.36	64.1	2.05
208	2.81	7.07	0.96	64.8	2.05	84.2	1.12	67.1	2.08
191	2.58	7.15	0.97	64.8	2.05	85.9	1.14	68.7	2.08
202	2.65	7.55	0.99	67.9	2.11				
199	2.61	7.44	0.98	67.9	2.11				
227	2.95	7.88	1.02	70.5	2.13				
227	2.95	8.09	1.05	70.5	2.13				

TABLE LXV

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: PLASKON 911

Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
880 Sized Roving									
138	1.88	6.73	0.92	63.2	2.03	29.5	0.43	59.8	1.90
126	1.72	6.52	0.89	63.2	2.03	29.5	0.43	59.8	1.90
163	2.08	7.71	0.98	71.1	2.17	54.8	0.71	69.1	2.15
160	2.04	7.57	0.96	71.1	2.17	48.9	0.63	68.7	2.14
32	0.42	1.03	0.13	74.6	2.16				
26	0.33	0.75	0.10	74.6	2.16				
Garan Finished Yarn									
187	2.52	7.66	1.03	64.9	2.05	99.8	1.40	61.4	1.97
184	2.49	7.56	1.02	64.9	2.05	108.3	1.43	65.5	2.09
157	2.01	7.93	1.02	71.3	2.16	88.9	1.16	68.7	2.13
62	0.79	6.68	0.86	71.3	2.16	87.5	1.12	69.5	2.16
48	0.61	6.58	0.84	73.3	2.18				
47	0.60	6.63	0.84	73.3	2.18				

TABLE LXVI

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: BUTON

Buton Sized Roving									
Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
76	1.23	5.50	0.89	55.5	1.71	20.4	0.34	53.5	1.68
73	1.18	5.38	0.87	55.5	1.71	34.3	0.51	62.7	1.86
106	1.55	5.59	0.82	62.1	1.89	25.6	0.38	65.5	1.89
98	1.44	5.55	0.81	62.1	1.89	40.9	0.56	72.5	2.03
114	1.67	6.50	0.95	65.5	1.89				
106	1.55	6.32	0.93	65.5	1.89				
118	1.69	7.52	1.08	67.3	1.93				
114	1.63	6.15	0.88	67.3	1.93				
A-172 Finished Yarn									
145	2.03	6.77	0.95	63.8	1.98	63.0	0.87	65.0	2.00
141	1.97	6.84	0.96	63.8	1.98	69.3	0.96	65.0	2.00
141	1.93	7.18	0.98	66.9	2.02	61.4	0.82	71.1	2.08
139	1.91	7.03	0.96	66.9	2.02	55.4	0.74	71.1	2.08
140	1.86	7.72	1.03	71.1	2.08				
136	1.81	7.43	0.99	71.1	2.08				

TABLE LXVII

INITIAL SCREENING STUDY PROPERTIES OF PARALLEL STRAND BARS

RESIN: ISOLITE 761-A

Flexural Properties						Compressive Properties			
Strength 10^3 psi	Specific Value 10^6 in.	Modulus 10^6 psi	Specific Value 10^8 in.	Glass Volume %	Specific Gravity	Strength 10^3 psi	Specific Value 10^6 in.	Glass Volume %	Specific Gravity
880 Sized Roving									
160	2.48	5.70	0.73	50.0	1.79	29.4	0.46	47.1	1.78
159	2.46	5.88	0.91	50.0	1.79	42.2	0.66	47.0	1.78
188	2.64	6.66	0.94	60.9	1.97	20.9	0.31	55.3	1.85
176	2.48	6.71	0.94	60.9	1.97	31.2	0.47	55.3	1.85
96	1.36	6.46	0.92	63.6	1.95				
90	1.28	6.48	0.92	63.6	1.95				
196	2.81	7.70	1.10	64.9	1.93				
97	1.39	7.29	1.04	64.9	1.93				
Garan Finished Yarn									
133	1.91	6.47	0.93	56.1	1.93	69.3	1.01	54.1	1.90
112	1.61	6.20	0.89	56.1	1.93	57.3	0.83	54.2	1.90
129	1.80	6.83	0.96	59.9	1.98	83.1	1.18	57.0	1.95
128	1.79	6.83	0.96	59.9	1.98	63.3	0.90	57.4	1.95
143	1.96	7.41	1.02	63.1	2.02	70.8	0.98	61.7	2.01
138	1.89	7.27	1.00	63.1	2.02	80.9	1.11	61.9	2.01
137	1.84	7.66	1.02	66.6	2.06	82.8	1.12	66.2	2.05
131	1.76	7.73	1.04	66.6	2.06	76.5	1.03	65.4	2.05

TABLE LXVIII

PROPERTIES OF PARALLEL STRAND BARS
EFFECT OF MATERIAL AND PROCESS VARIABLES
WITH PARAPLEX AP-174 RESIN

Specimen No.	Flexural Properties				Ignition Loss %	Spec. Grav.	Glass Vol.%
	Strength 10^3 psi		Modulus 10^6 psi				
	Dry	2 HB	Dry	2 HB			
1	216.0	190.6	6.85	6.61	23.7	2.05	61.2
2	248.8	224.7	8.15	7.80	17.2	2.15	69.8
3	224.9	203.5	7.21	7.10	23.1	2.06	62.4
4	242.9	229.8	7.66	7.31	19.9	2.09	65.5
5	246.9	210.3	7.93	7.59	21.6	2.08	63.9
6	211.6	205.4	6.79	6.77	27.6	1.98	56.3
7	237.1	236.0	7.44	7.54	23.7	2.05	61.2
8	225.4	221.2	7.26	7.24	24.7	2.02	59.8
9	238.7	206.2	7.63	8.03	18.6	2.07	66.1
10	260.0	233.8	7.15	7.22	20.1	2.09	65.1
11	273.8	236.8	7.82	8.02	18.8	2.09	66.4
12	237.5	192.9	6.83	7.02	23.1	2.04	61.5
13	281.2	229.0	7.03	7.50	18.2	2.14	68.6
14	255.1	91.8	7.80	7.80	13.6	2.21	74.7
15	249.1	208.9	6.63	6.85	20.7	2.11	64.7
16	255.6	211.7	7.80	7.91	12.2	2.21	76.0
17	201.1	194.4	5.85	7.06	30.1	1.94	53.3
18	235.6	240.5	7.35	7.89	21.4	2.07	63.8
19	206.1	198.1	6.00	6.38	26.2	2.02	58.5
20	231.1	238.3	6.96	7.65	21.4	2.06	63.6
21	236.0	238.7	6.86	7.76	18.1	2.13	68.3
22	203.1	188.6	5.95	6.38	25.9	2.01	58.3
23	225.5	216.4	6.55	7.52	19.6	2.11	66.6
24	211.6	209.0	6.25	7.18	23.3	2.04	61.4
25	238.7	83.6	6.77	7.26	13.8	2.18	73.7
26	212.7	199.7	6.07	7.45	18.7	2.13	67.8
27	228.8	241.6	6.51	8.09	13.2	2.21	75.1
28	224.3	212.6	5.47	6.88	20.4	2.08	64.4
29	206.7	191.1	5.72	6.74	25.3	1.96	57.3
30	254.2	214.9	6.27	7.71	22.5	2.02	61.5
31	248.9	200.1	5.90	6.74	25.4	1.97	57.7
32	223.8	240.8	6.44	8.41	18.1	2.10	67.5

TABLE LXVIII (Concluded)

PROPERTIES OF PARALLEL STRAND BARS
EFFECT OF MATERIAL AND PROCESS VARIABLES
WITH PARAPLEX AP-174 RESIN

Specimen No.	Flexural Properties				Ignition Loss %	Spec. Grav.	Glass Vol. %
	Strength 10^3 psi		Modulus 10^6 psi				
	Dry	2 HB	Dry	2 HB			
33	193.3	194.5	5.09	6.88	22.3	2.05	62.3
34	196.9	211.3	5.25	7.05	26.4	1.97	56.9
35	226.4	241.8	5.35	7.46	21.5	2.06	62.9
36	199.9	198.5	5.28	7.14	18.8	2.14	68.3
37	164.9	-	4.17	-	32.5	1.90	50.3
38	204.7	-	5.04	-	22.8	2.05	62.1
39	209.7	-	4.78	-	20.3	2.09	65.4
40	180.8	-	4.54	-	22.5	2.04	62.1

TABLE LXIX

PROPERTIES OF PARALLEL STRAND BARS
EFFECT OF PROCESS VARIABLES WITH
PARAPLEX AP-174 RESIN AND 880 SIZED ROVING

Specimen No.	Flexural Properties After 2-Hour Boil		Ignition Loss %	Spec. Grav.	Glass Volume %
	Strength, 10^3 psi	Modulus, 10^6 psi			
1	212.0	6.47	21.7	2.06	63.3
2	214.5	6.86	19.2	2.10	66.6
3	236.0	7.26	17.3	2.16	69.9
4	239.5	7.52	17.2	2.16	70.1
5	244.0	7.64	14.2	2.20	73.9
6	244.5	7.64	15.3	2.20	73.2
7	252.5	7.66	14.6	2.20	74.3
8	247.5	7.66	13.2	2.20	75.2
9	214.5	6.82	19.1	2.14	67.8
10	241.0	6.99	17.8	2.15	69.2
11	245.0	7.19	14.8	2.21	73.8
12	236.5	8.13	12.2	2.22	76.6

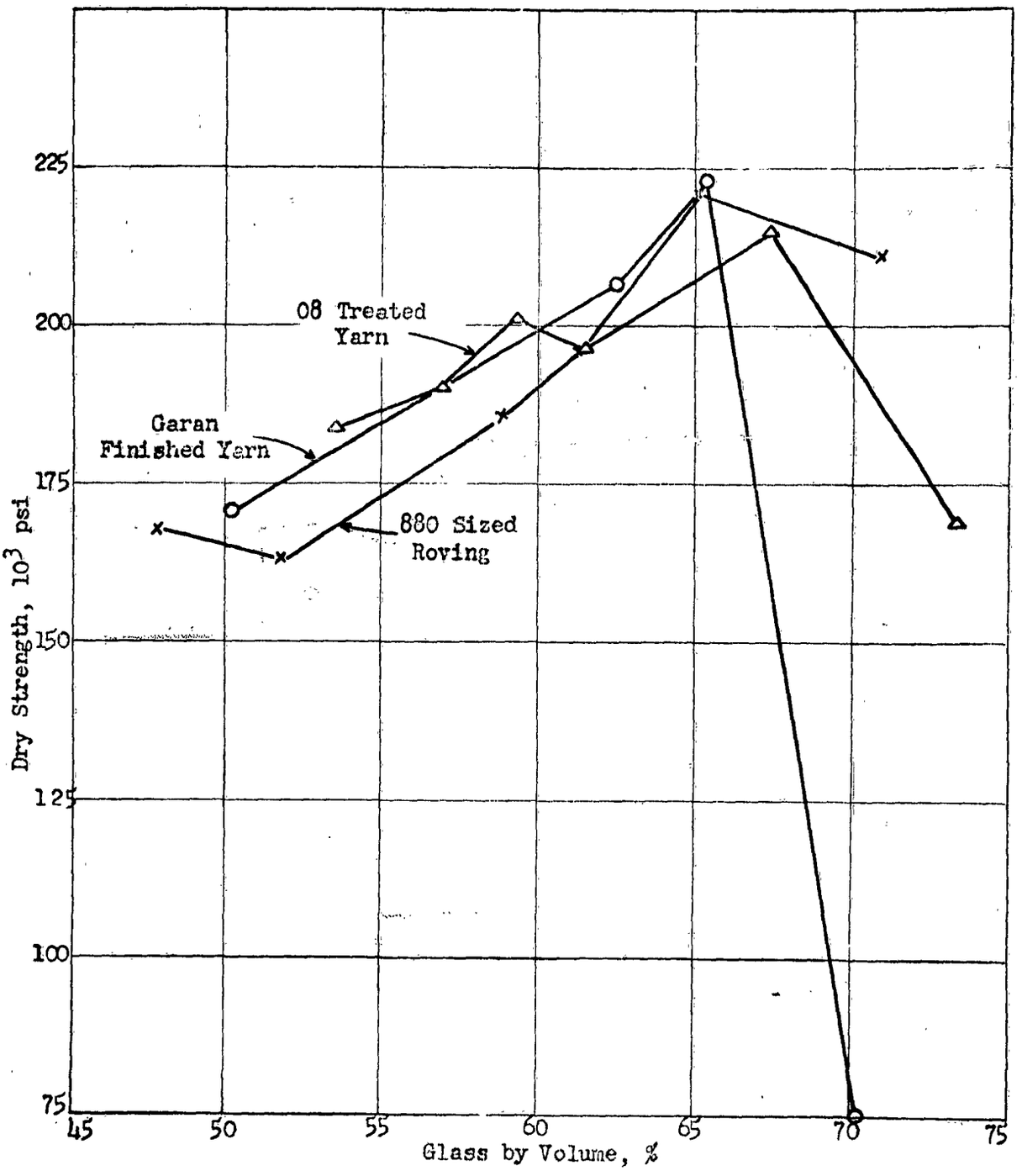

Figure 17 - The Effect of Glass Content on Flexural Strength
"E" Glass Parallel Reinforced Bars - Paraplex P-43 Resin

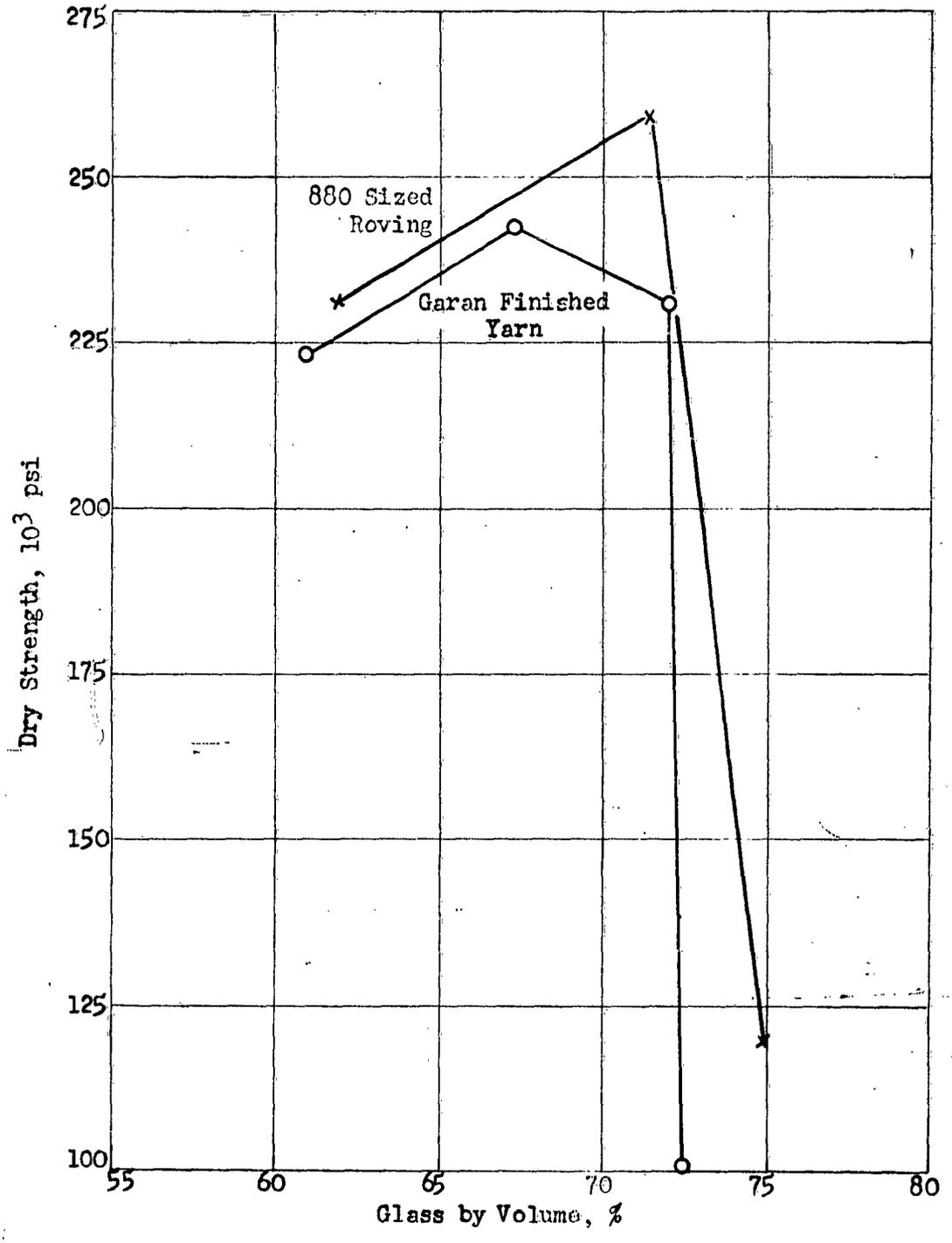

Figure 18 - The Effect of Glass Content on Flexural Strength "E" Glass Parallel Reinforced Bars - Paraplex A-174 Resin

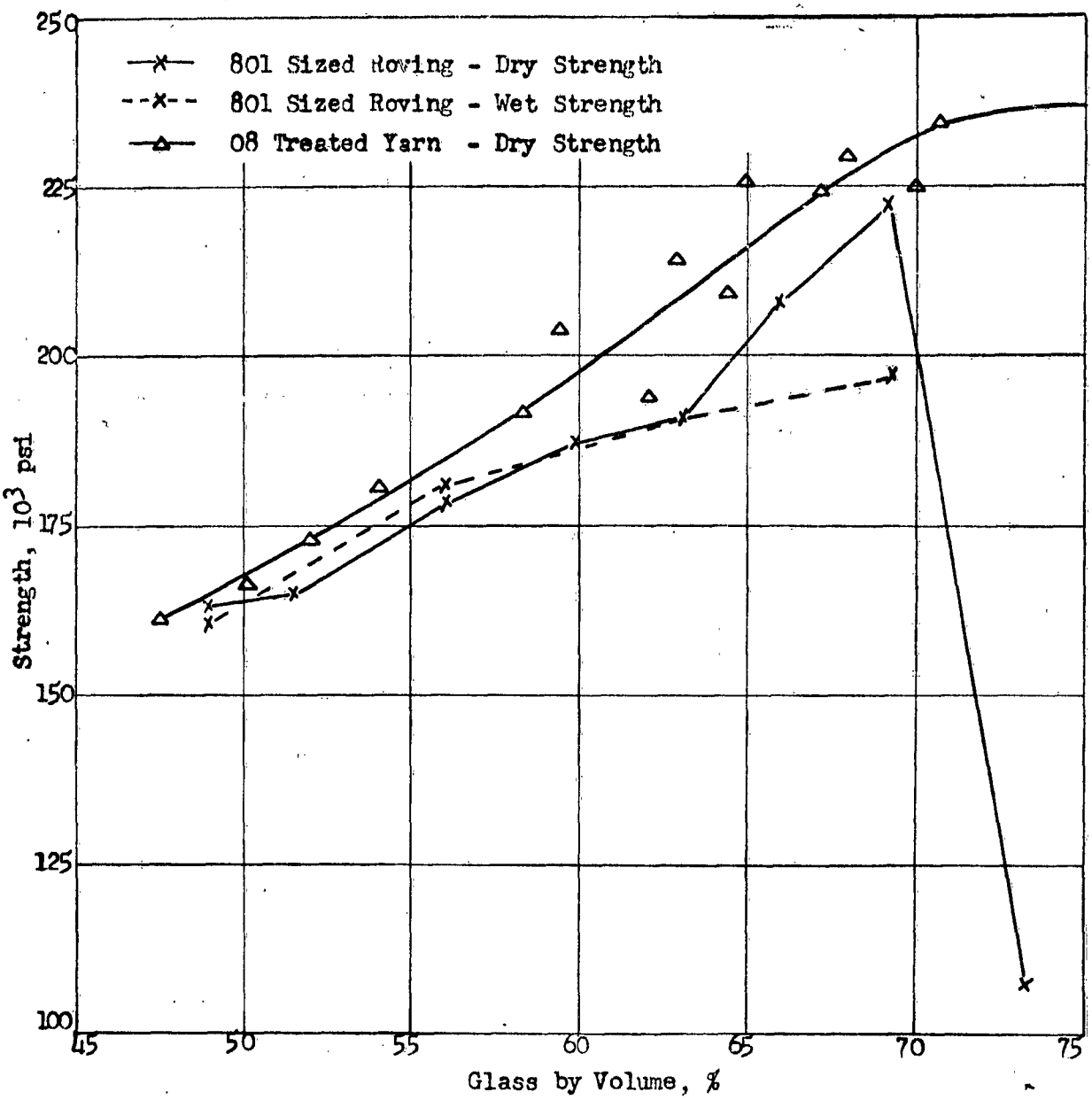

Figure 19 - The Effect of Glass Content on Flexural Strength "E" Glass Parallel Reinforced Bars - Epon 828/CL Resin

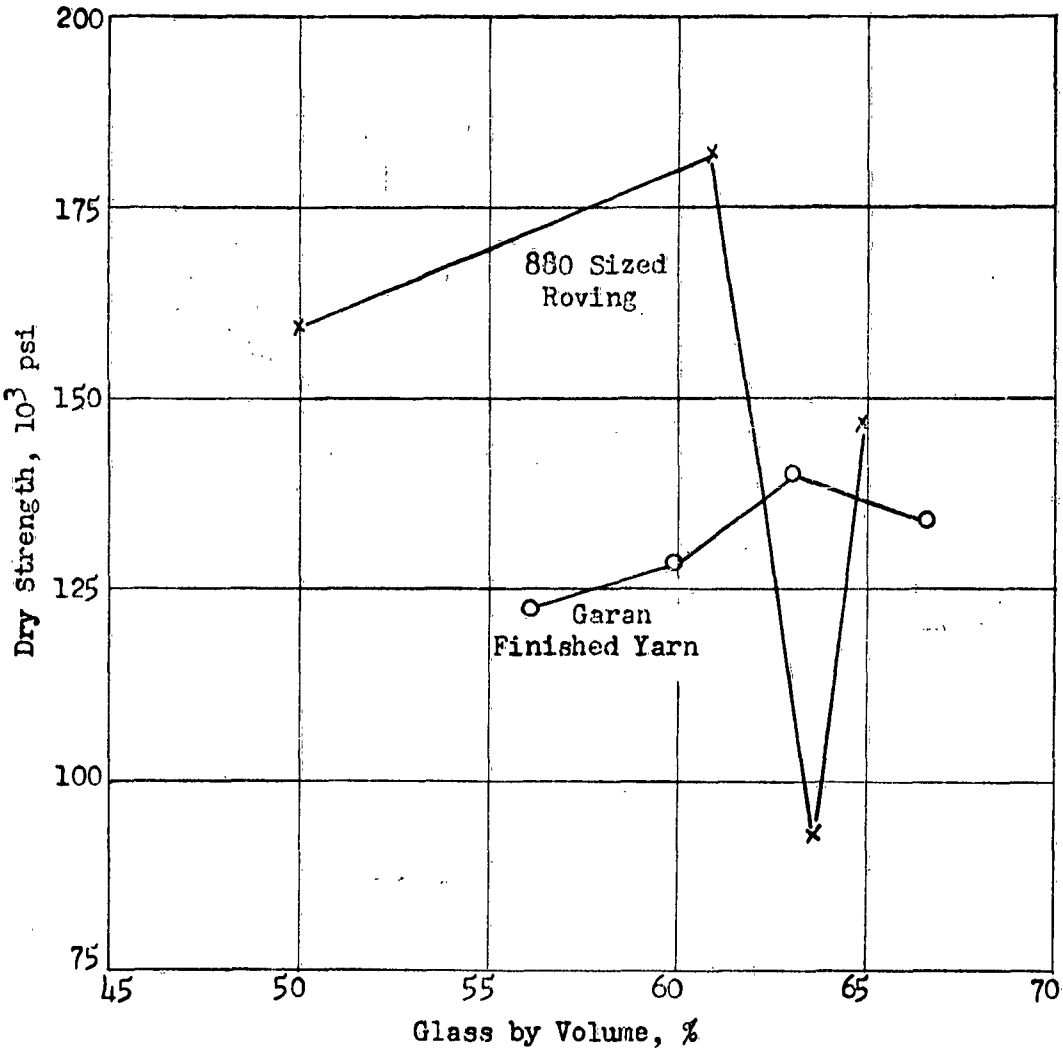

Figure 20 - The Effect of Glass Content on Flexural Strength
"E" Glass Parallel Reinforced Bars - Isolite 761-A Resin

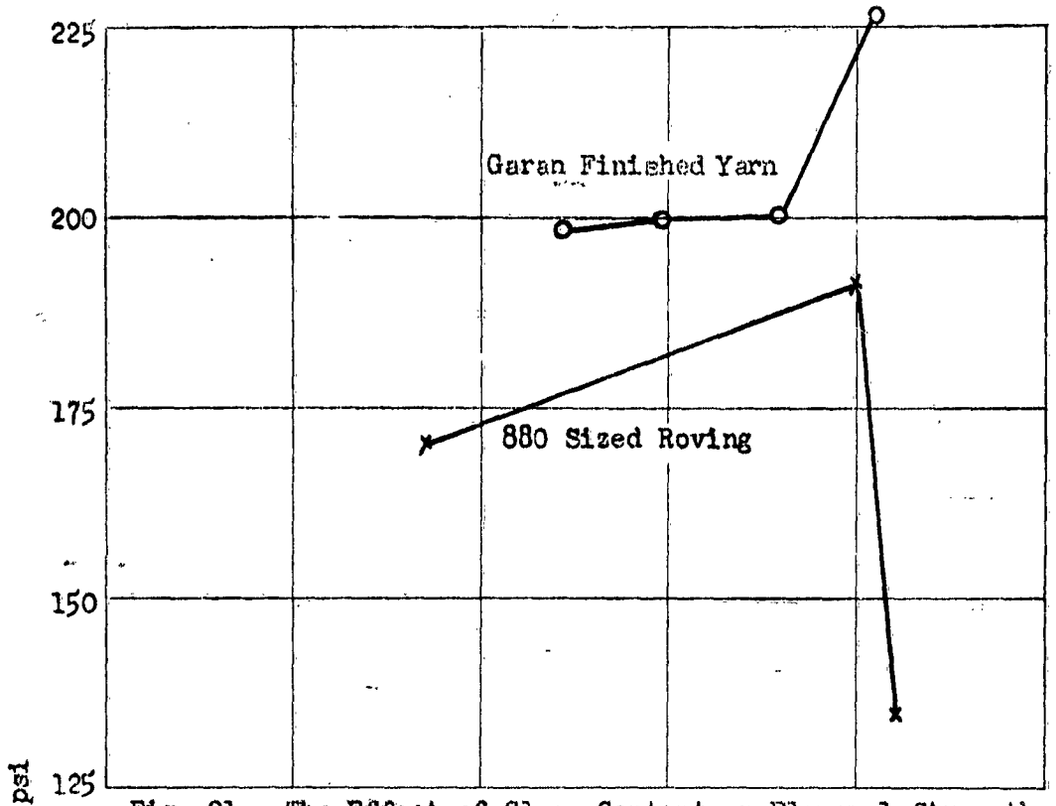

Fig. 21 - The Effect of Glass Content on Flexural Strength "E" Glass Parallel Reinforced Bars - Atlac 382X Resin plus 10% Methacrylic Acid

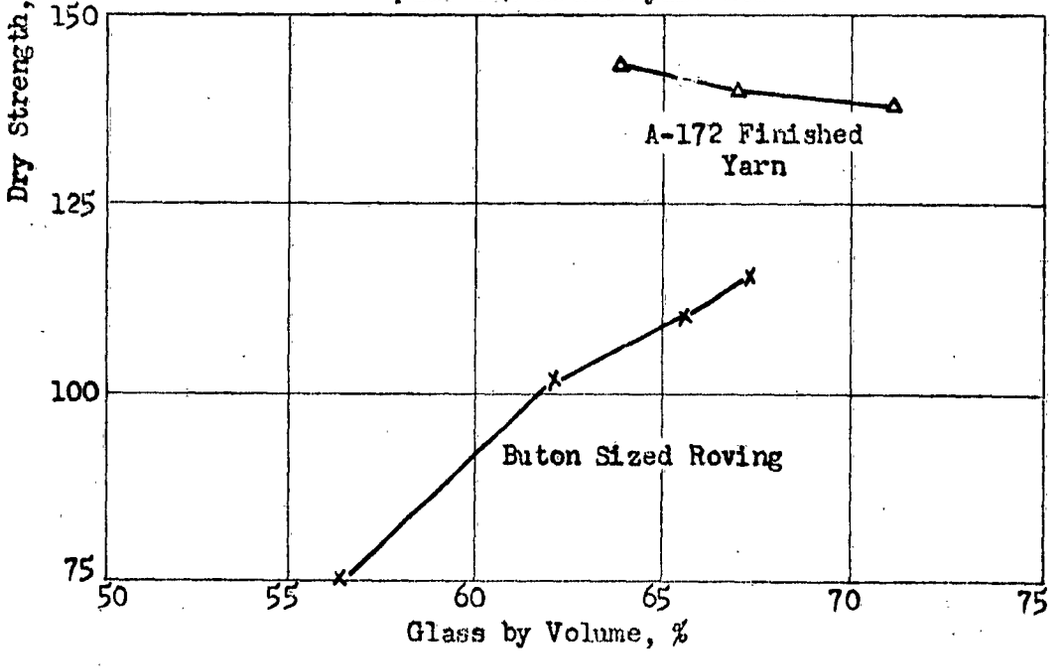

Figure 22 - The Effect of Glass Content on Flexural Strength "E" Glass Parallel Reinforced Bars - Buton Resin

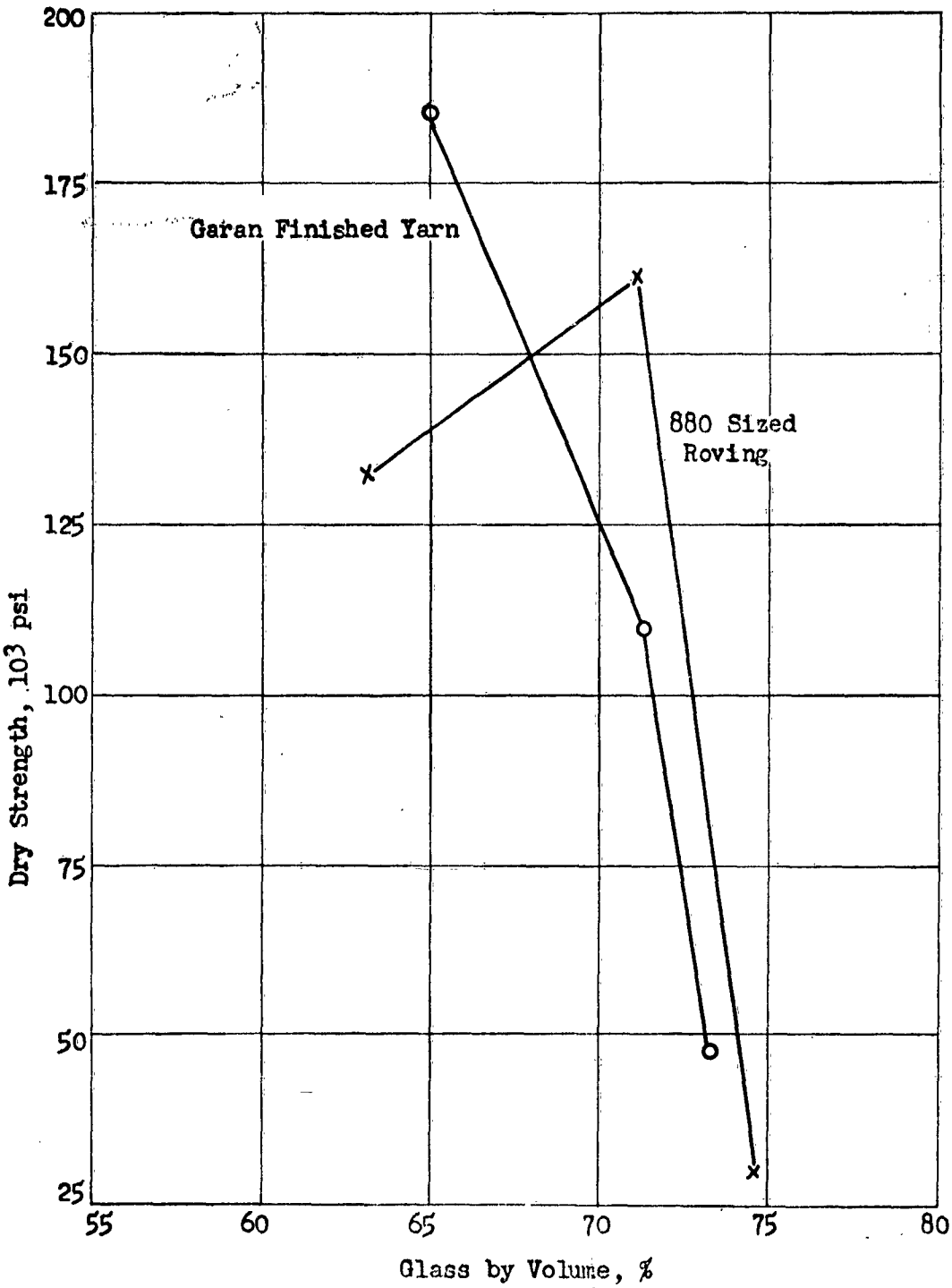

Figure 23 - The Effect of Glass Content on Flexural Strength
"E" Glass Parallel Reinforced Bars - Plaskon 911 Resin

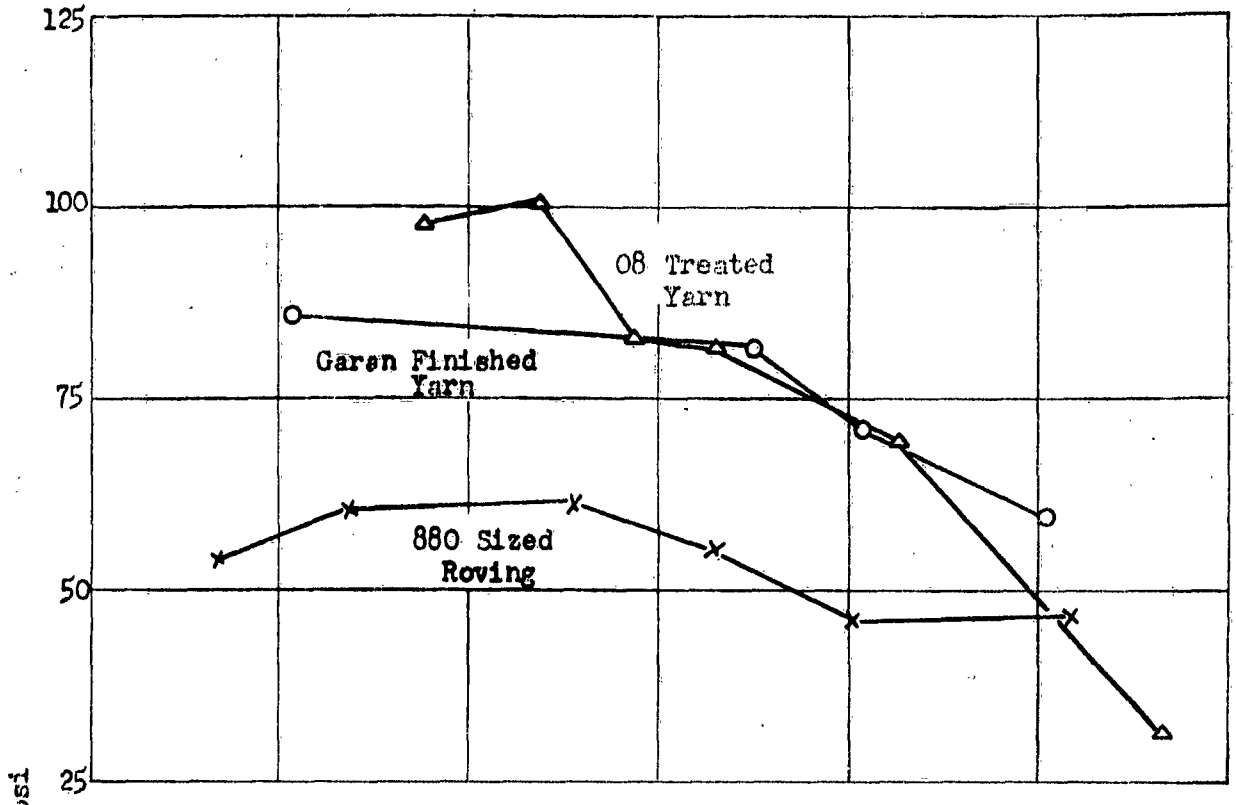

Figure 24 - The Effect of Glass Content on Compressive Strength "E" Glass Parallel Reinforced Bars - Paraplex P-43 Resin

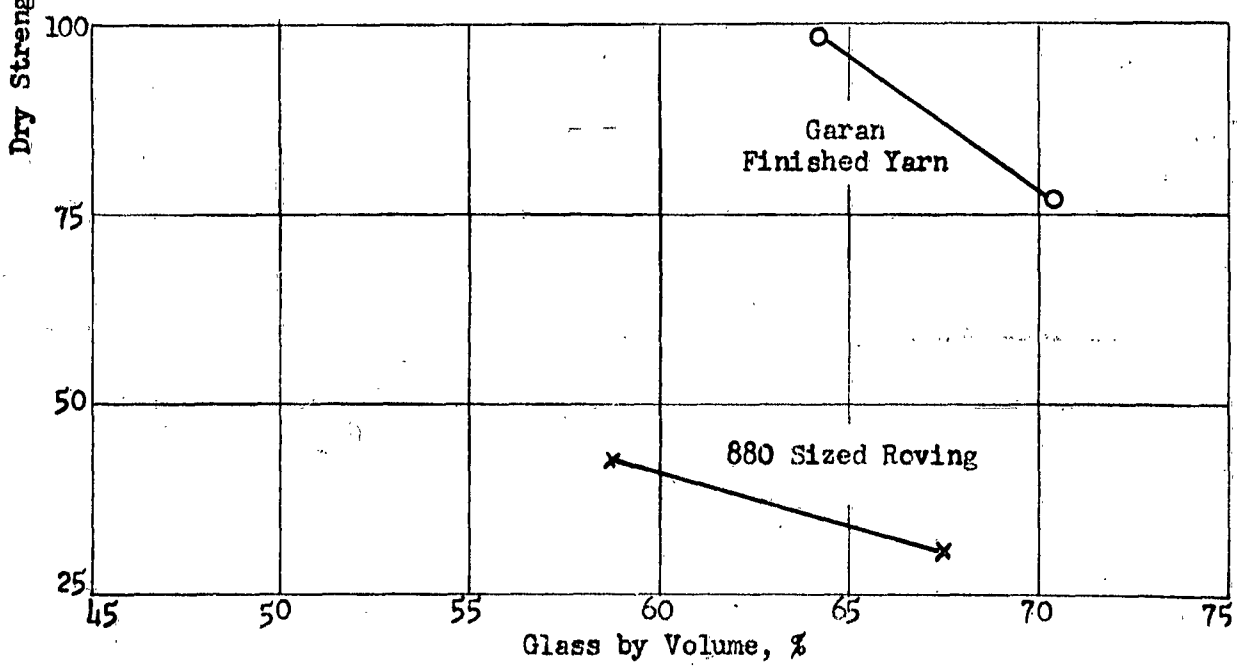

Figure 25 - The Effect of Glass Content on Compressive Strength "E" Glass Parallel Reinforced Bars - Paraplex A-174 Resin

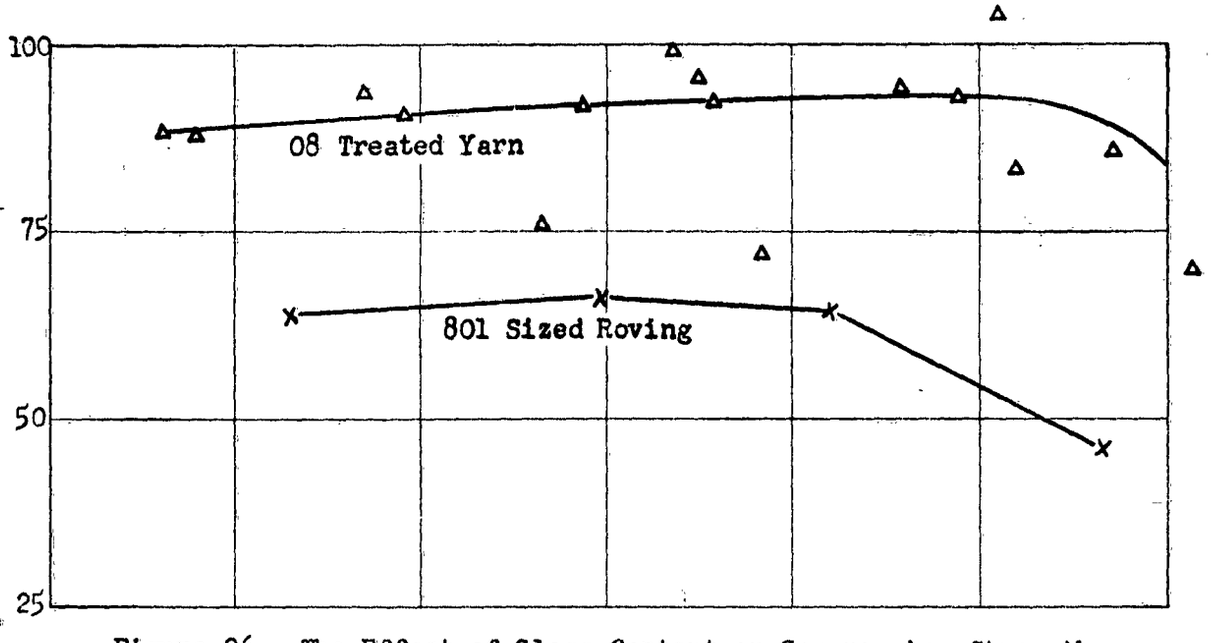

Figure 26 - The Effect of Glass Content on Compressive Strength
"E" Glass Parallel Reinforced Bars - Epon 828/CL Resin

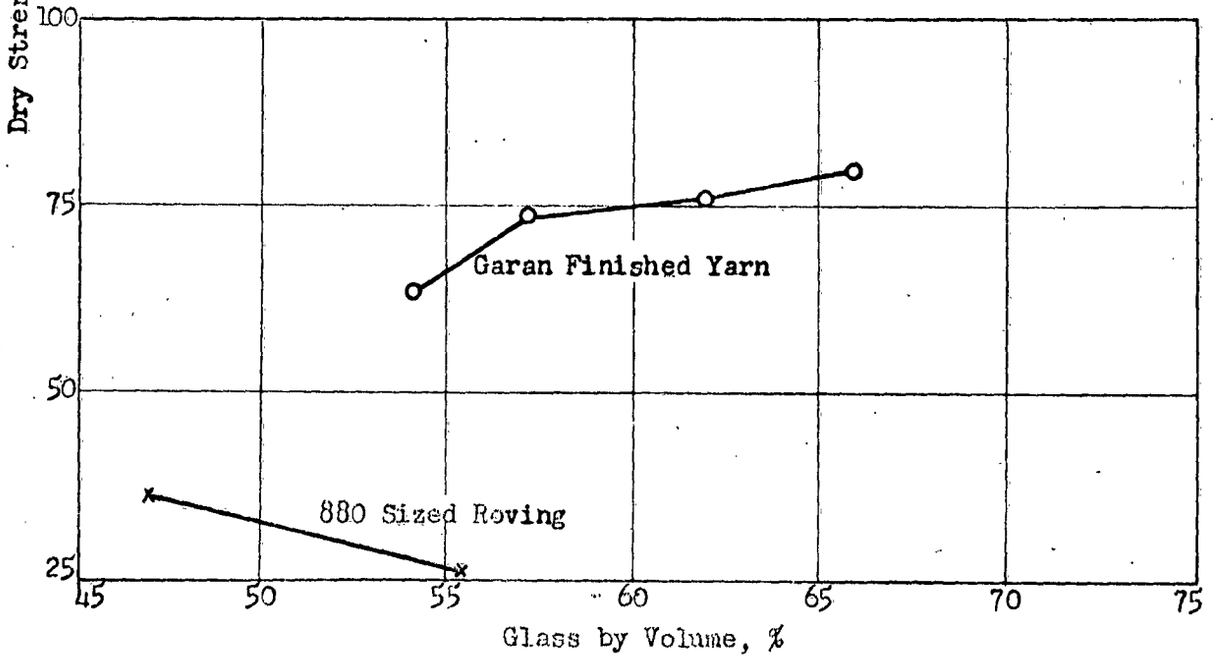

Figure 27 - The Effect of Glass Content on Compressive Strength
"E" Glass Parallel Reinforced Bars - Isolite 761-A Resin

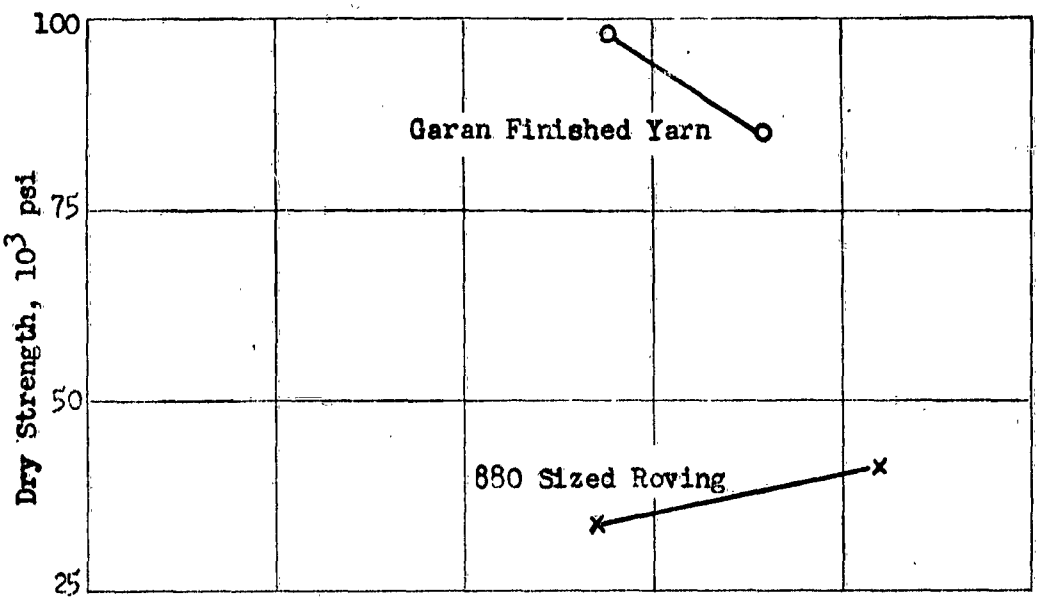

Figure 28 - The Effect of Glass Content on Compressive Strength "E" Glass Parallel Reinforced Bars - Atlac 382X Resin plus 10% Methacrylic Acid

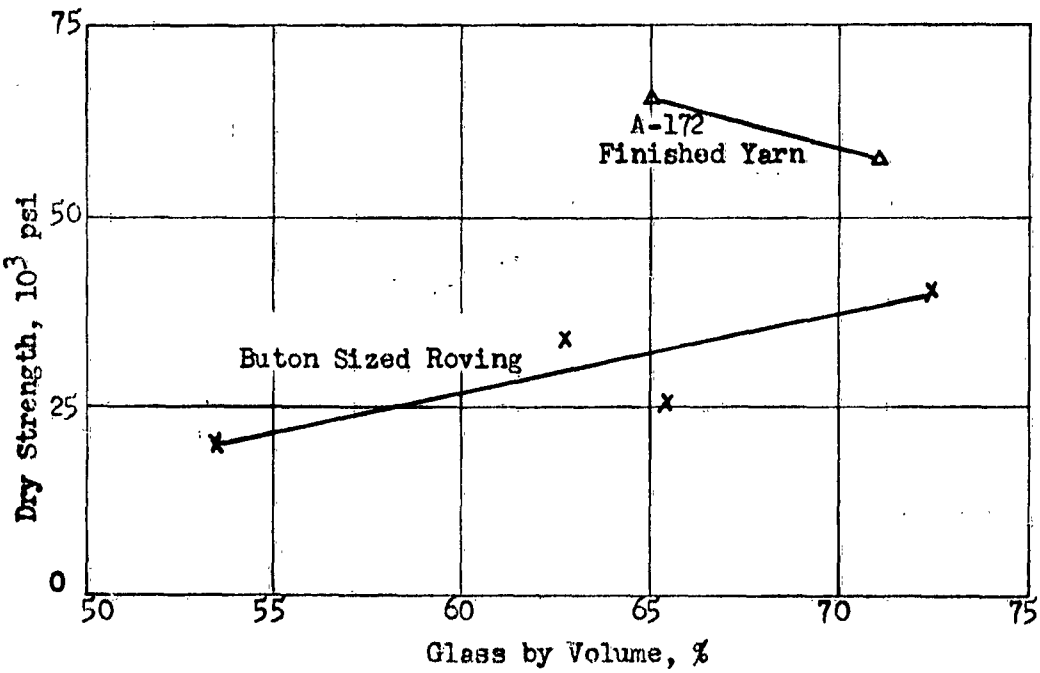

Figure 29 - The Effect of Glass Content on Compressive Strength "E" Glass Parallel Reinforced Bars - Buton Resin

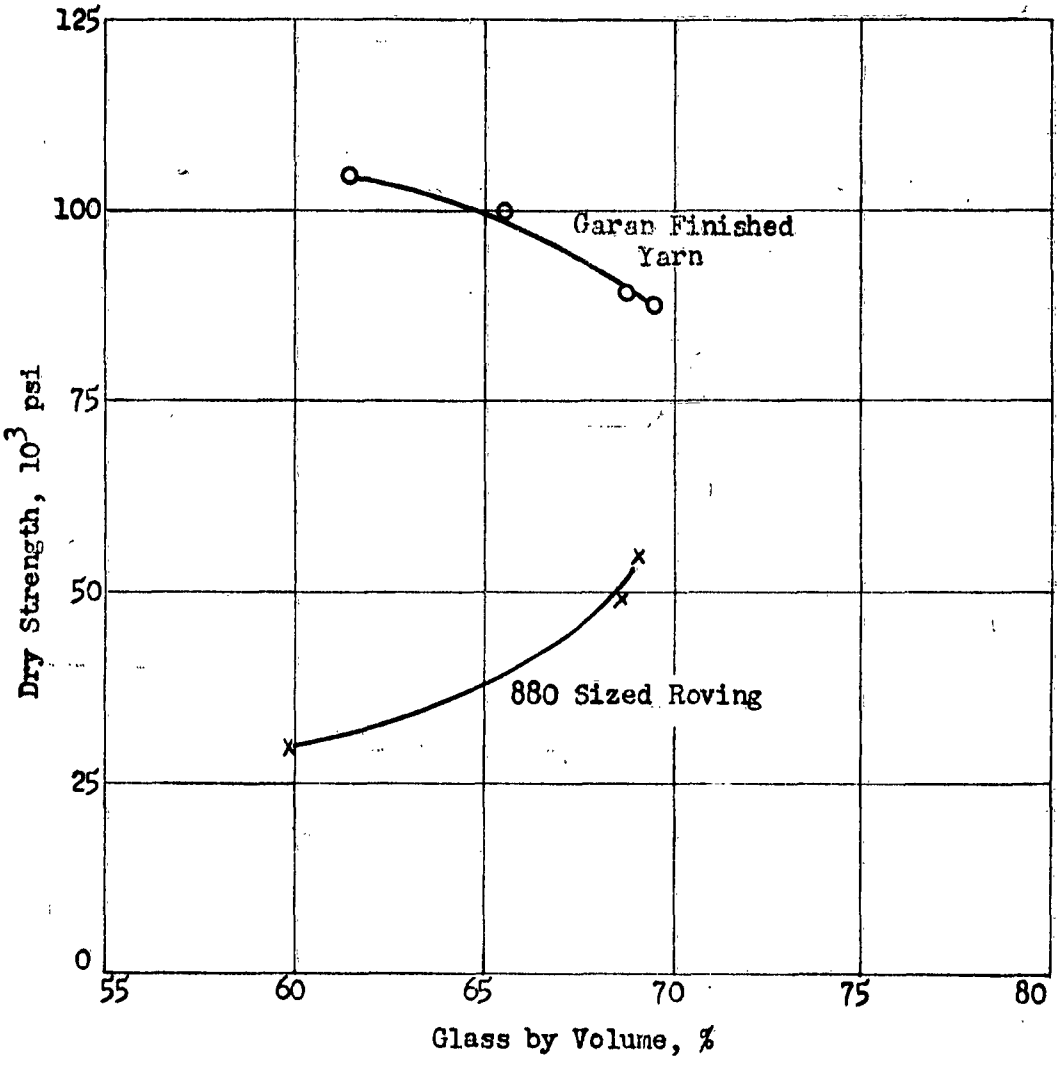

Figure 30 - The Effect of Glass Content on Compressive Strength "E" Glass Parallel Reinforced Bars - Plaskon 911 Resin

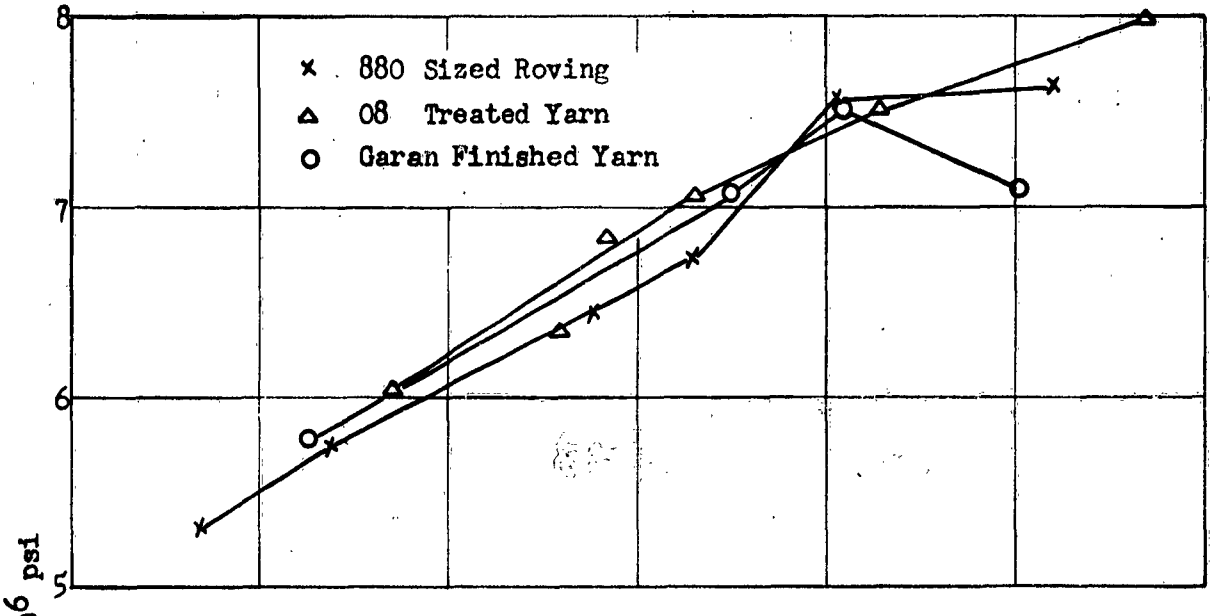

Figure 31 - The Effect of Glass Content on Flexural Modulus
"E" Glass Parallel Reinforced Bars - Paraplex P-43 Resin

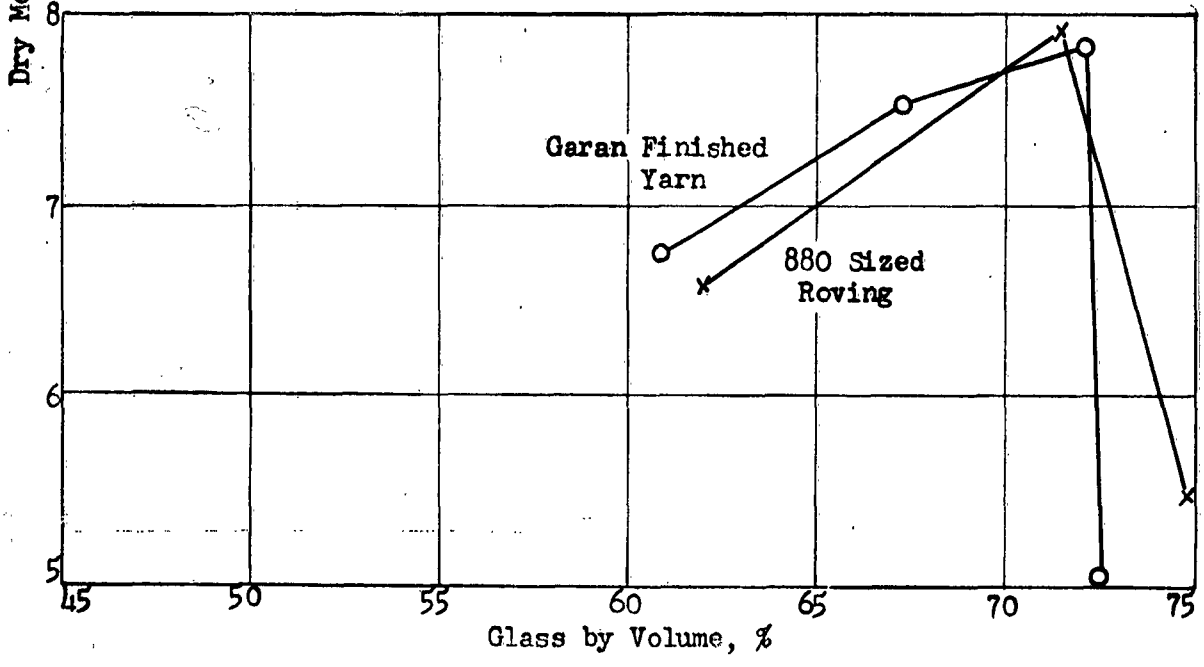

Figure 32 - The Effect of Glass Content on Flexural Modulus
"E" Glass Parallel Reinforced Bars - Paraplex A-174 Resin

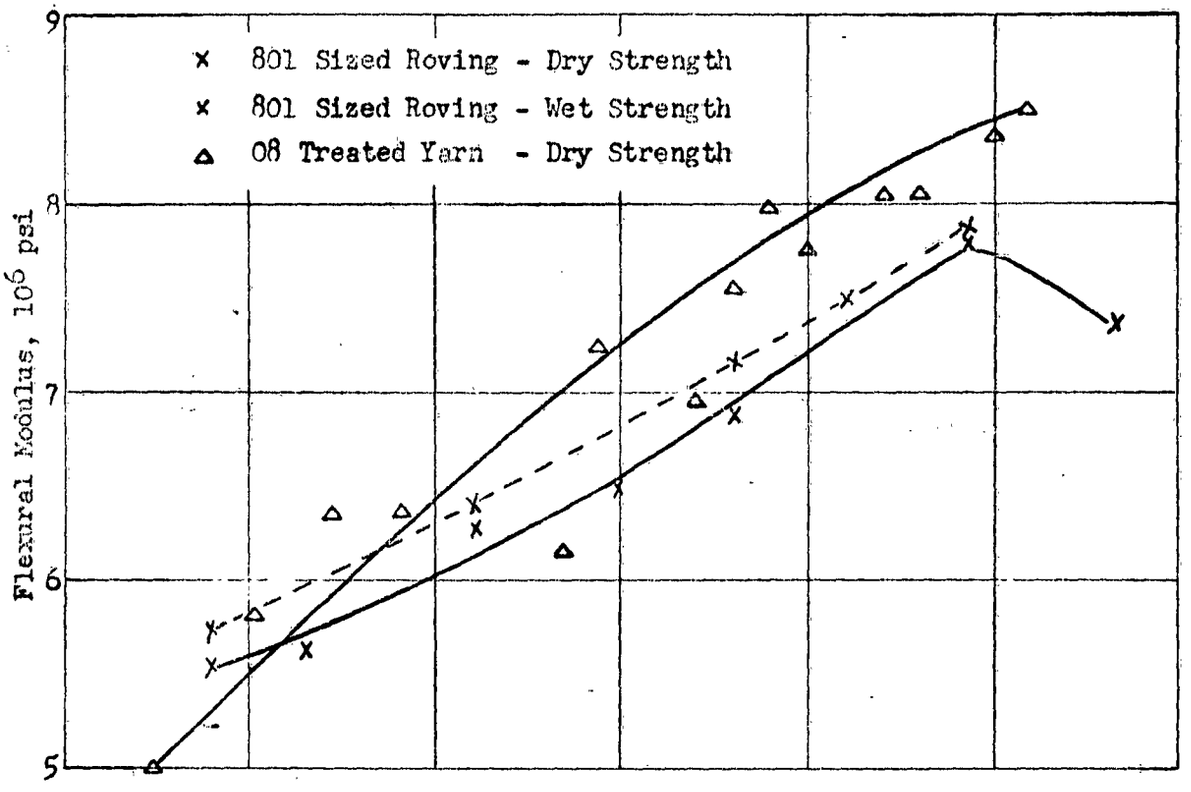

Figure 33 - The Effect of Glass Content on Flexural Modulus
"E" Glass Parallel Reinforced Bars - Epon 828/CL Resin

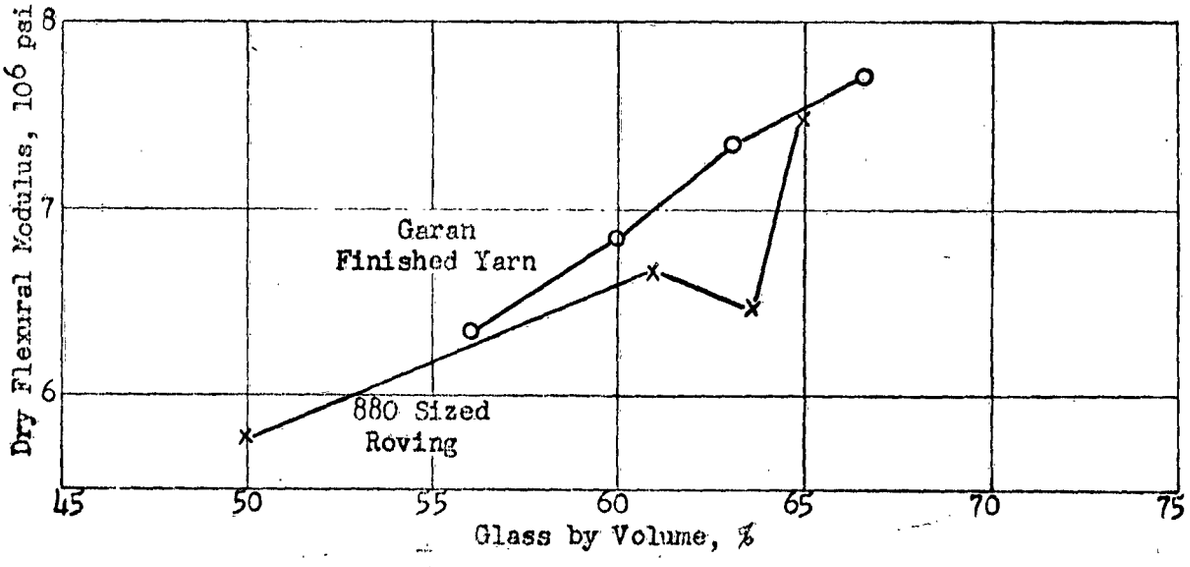

Figure 34 - The Effect of Glass Content on Flexural Modulus
"E" Glass Parallel Reinforced Bars - Isolite 761-A Resin

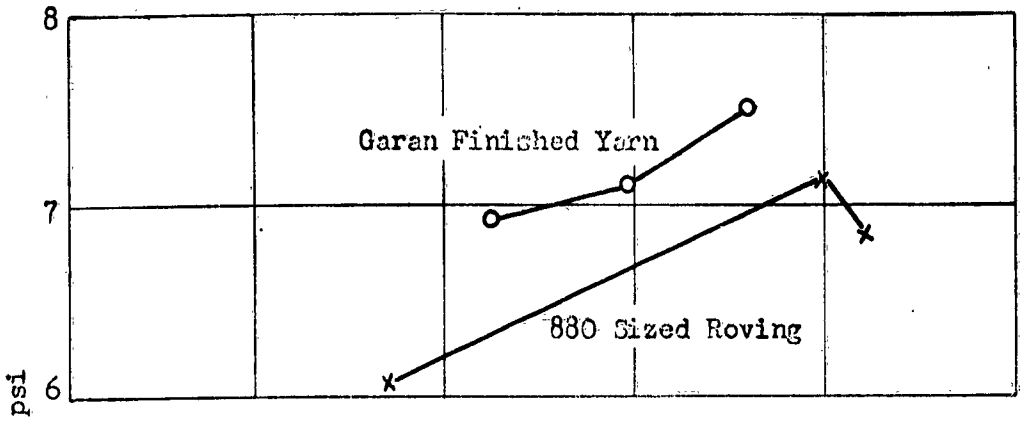

Figure 35 - The Effect of Glass Content on Flexural Modulus "E" Glass Parallel Reinforced Bars - Atlac 382X Resin plus 10% Methacrylic Acid

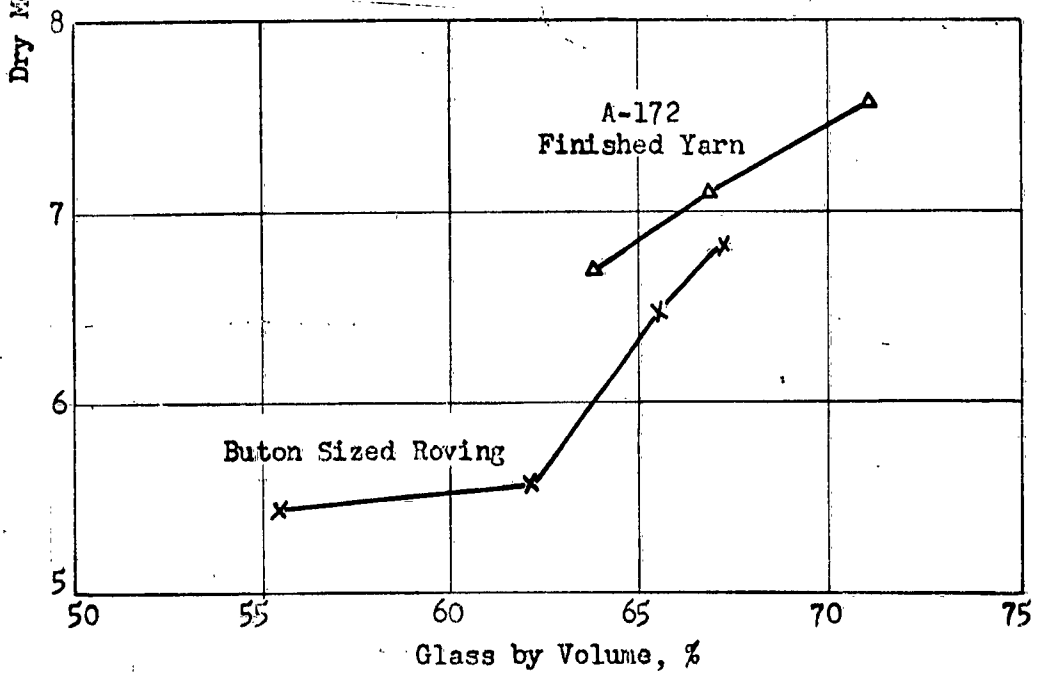

Figure 36 - The Effect of Glass Content on Flexural Modulus "E" Glass Parallel Reinforced Bars - Buton Resin

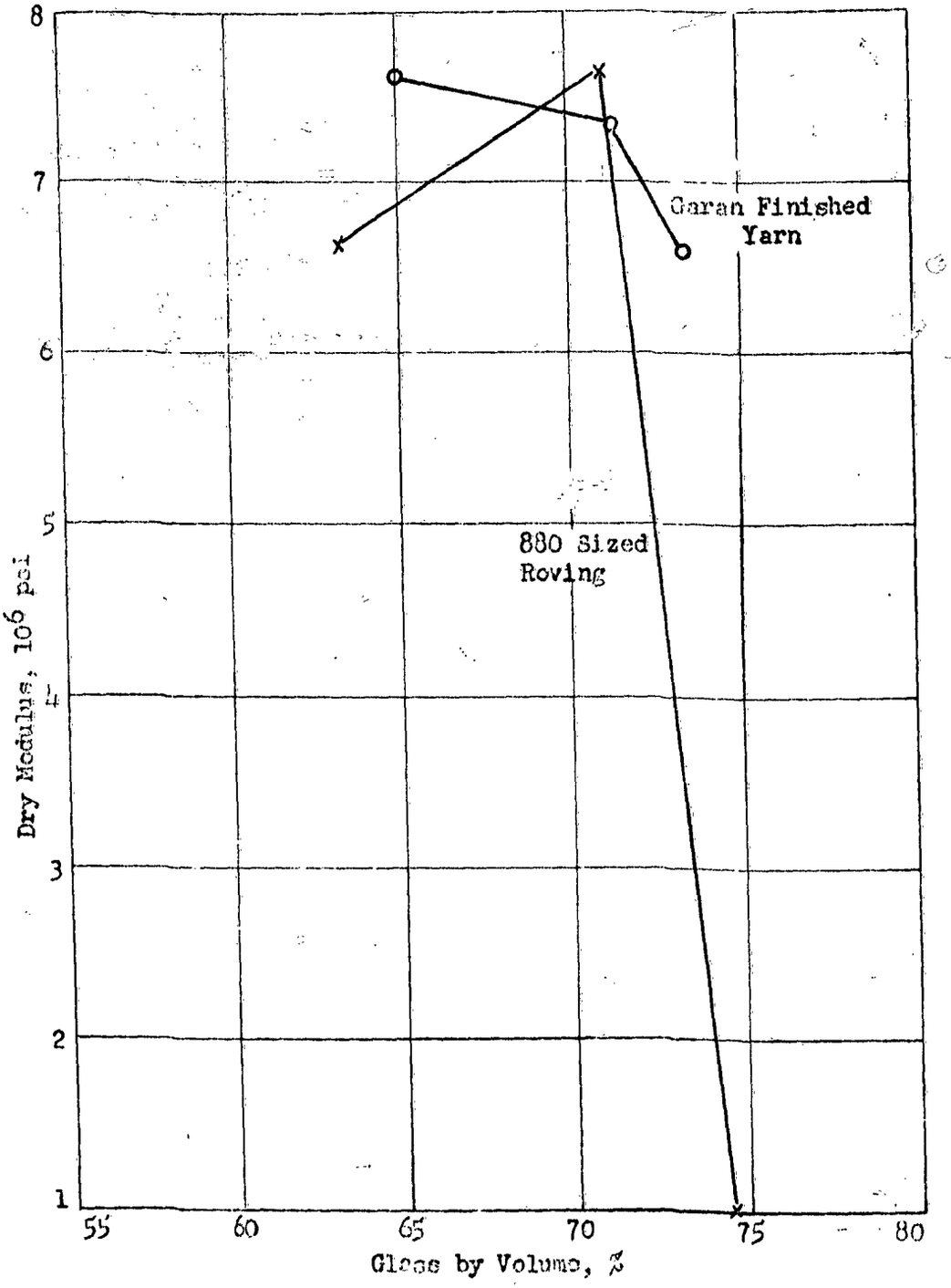

Figure 37 – The Effect of Glass Content on Flexural Modulus "E" Glass Parallel Reinforced Bars - Plaskon 911 Resin